**Plant, macrolichen and moss community structure**

**and species richness in the coastal barrens of Nova Scotia**

By

Erica C. Oberndorfer

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## Abstract

Coastal barrens in Nova Scotia are an understudied habitat type characterised by short, predominantly ericaceous vegetation, sparse tree cover, exposed bedrock, areas of bog, and stressful climatic conditions. Six coastal barrens were selected along the Atlantic coast. Twenty 1 x 1 m plots at each site were sampled for vascular plants, macrolichens and mosses, and environmental factors, including substrate nutrient and moisture levels, exposure, and substrate depth. One hundred and seventy-six species were recorded over the 6 sites (105 vascular species, 43 macrolichen species, 28 moss species), 11 of which are provincially rare (S1, S2). Community composition differed among sites, and was related to distance to coast, substrate depth, substrate moisture, and vegetation height. Species richness was influenced by moisture conditions, exposure and substrate depth. Conservation efforts should protect gradients of these environmental factors in order to protect a diversity of plant types, which respond variously to these factors.

Date: October 5, 2006

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## Introduction

### Foreword and objective

The coastline of mainland Nova Scotia and Cape Breton is over 7000 km long. Even in the interior of Nova Scotia, the ocean is never more than 60 km away. Culturally, economically and politically, this province has been definitively shaped by the sea.

The focus of much scientific research in Nova Scotia has also, not surprisingly, been on marine systems. There is a large body of knowledge on offshore and benthic systems, and on nearshore habitats such as salt marshes. Certain high-profile terrestrial systems such as the Acadian forest and the coastal plains have also been the focus of lengthy research efforts and, as a result, conservation planning with respect to these systems is increasingly well-informed. Research on habitats that are of interest to the forestry and mining sectors is also well-supported.

Coastal barrens, on the other hand, have received little to no research attention in Nova Scotia. This coastal system forms a vital part of the natural and cultural landscape of Nova Scotia--possibly no site in the Maritimes is better known than Peggy's Cove, which is nested in one of the largest coastal barren complexes in the province. Coastal barrens occur near large population centers such as Halifax. They are highly accessible by foot and, lamentably, ATVs. Many coastal barrens occur on Crown land or in protected areas. All of these reasons would seem to suggest that this system should be well-known to researchers, and yet, to date and to the best of my knowledge, there has never been a major study on the coastal barrens of Nova Scotia. The overarching

objective of this research is therefore to collect and compile data that can inform conservation debate in this province.

**Heathlands: an overview**

Coastal barrens have received more attention in other parts of the world, where they are more commonly referred to as "heathlands." There is a history of heathland research in the United Kingdom and mainland Europe, on both inland and coastal heathland systems. In North America, heathlands and their origins and maintenance have also been investigated in New England and Newfoundland (Mallik 1995; Dunwiddie *et al.* 1996; Foster and Motzkin 1998; Motzkin and Foster 2002; Latham 2003; Lorimer and White 2003).

Heathlands are a shrub-dominated habitat type that occur where prevailing conditions are too stressful for tree growth, such as at extremes of the soil moisture gradient, at high elevation and in areas of marine salt spray (Latham 2003). Other habitat types in North America that exhibit similar shrub dominance include tundra, desert scrub, alvars, and alpine zones. Globally, shrub habitats include chaparral, matorral, garringue, maqui, fynbos, and mallee (Latham 2003). Although heathland systems can exhibit a range of shrub or grass dominance, it is generally agreed that heathland systems are all typically acidic, nutrient-poor habitat types dominated by ericaceous vegetation (Webb 1998; Schmidt *et al.* 2004; Piessens *et al.* 2006).

Heathlands and bogs often co-occur in a patchwork of habitat types with no obvious pattern (Wells 1981). Heathands and bogs share a number of common species, including Labrador Tea (*Rhodedendron groenlandicum*), Sheep Laurel (*Kalmia*

*angustifolia*) and Black Crowberry (*Empetrum nigrum*). When defining or cartographically delineating heathlands, it is therefore often difficult or impossible to separate bogs from heathlands by vegetation type. Topographically, bogs and heathlands may also be very similar (Graniero and Price 1999). Barren-bog complexes are known to occur in areas of cool, wet climate, including Alaska, Newfoundland, Ireland, northern Scotland, and parts of England and Wales (Graniero and Price 1999). For the purposes of this study, "areas of bog" refers to areas with poor drainage and greater depth to bedrock, as compared to coastal barren areas.

Heathlands known to occur in New England appear to differ from heathlands in the aforementioned regions. Most of the literature describes the heathlands of New England as shrub- and grass-dominated open habitats (e.g. Dunwiddie *et al.* 1996; Foster and Motzkin 1998; Motzkin and Foster 2002). Heathlands also frequently contain patches of rock outcrops where underlying bedrock is exposed. These outcrops and glacial erratics are dominated by lichen communities.

As noted by Tack *et al.* (1993), historically, there has been a successional relationship between heathlands and forest. Current heathlands are often set in a landscape matrix that consists primarily of forest, and pollen studies have shown that heathlands can also occupy areas that once were forested (Motzkin and Foster 2002). Conversely, forested areas also currently occur on former heathland (Foster and Motzkin 1998; Motzkin and Foster 2002; Piessens and Hermy 2005). Forest species with woody, clonal growth are known to be more persistent in heathland vegetation over time (Piessens and Hermy 2006). Forest understory species have been observed to persist in the coastal barrens of Nova Scotia, including Canada Mayflower (*Maianthemum*

*canadense*), Bunchberry (*Cornus canadensis*) and Red-Stem Moss (*Pleurozium schreberi*) (Lundholm and Oberndorfer 2004, unpublished data). Likewise, many heathland species are known to have a persistent seed bank, and can stay dormant under a closed forest canopy until prevailing conditions become more favourable for their reestablishment (Stieperaere and Timmerman 1983; Pywell *et al.* 1997; Bossuyt and Hermy 2003; Piessens *et al.* 2005). Consequently, these heathland species may have an "extinction debt," which is the delayed extirpation of species long after conditions have ceased to be favourable for their growth and reproduction (Tillman *et al.* 1994, Hanski and Ovaskainen 2002).

**Plant ecology of coastal barrens in Nova Scotia**

Three types of barrens are recognised in Nova Scotia by the Nova Scotia Museum (1997a) and are differentiated based on their proximity to the coast: coastal, highland and inland barrens. Regardless of this geographical distinction, classification done by the Nova Scotia Museum of Natural History describes these barrens generically. A "barren" is a "rocky heathland with dwarf shrub and lichen vegetation that occurs in Nova Scotia along the Atlantic coast as well as inland" (1997a, 464). Barrens are described as a patchwork habitat consisting of hummocks, exposed bedrock, stunted trees, and oligotrophic bog (Nova Scotia Museum 1997a).

All three barren types are said to share similar species, predominantly ericaceous vegetation and lichens, including *K. angustifolia*, Bearberry (*Arctostaphylos uva-ursi*), crowberries (*E. nigrum, E. eamesii, Corema conradii*), and Reindeer Lichen (*Cladonia* spp.), (Nova Scotia Museum 1997a). These and other barrens species are tolerant of

extreme environmental conditions, such as high winds, salt spray, temperature fluctuations, and periodic flooding and drought. Trees in this habitat are scarce and greatly reduced in size (Nova Scotia Museum 1997a).

Beyond these general observations, data about the relative abundance and distribution of coastal barren species are lacking. Furthermore, the number and location of sites visited in order to inform most of the Nova Scotia Museum documents are unknown. We are therefore unable to accurately comment on both site-specific plant communities and on the plant communities of coastal barrens in general, if such generalities exist. Site-level species data are important to our understanding of whether and how different barrens are floristically connected, and at what scale (regional or local) we need to direct conservation efforts.

Collecting these types of baseline data will facilitate future monitoring efforts, both at the community level and for target species. Species-at-risk research depends on abundance and distribution data, both of which are currently lacking for this system. Coastal barrens are known to contain several provincially rare species ranked S1 (extremely rare: five or fewer occurrences) or S2 (rare: six to twenty occurrences) (Atlantic Canada Conservation Data Centre 2006). These species include: Red Crowberry (*Empetrum eamesii*: S2); Northern Blueberry (*Vaccinium boreale*: S2); Oval-leaf Huckleberry (*V. ovalifolium*: S1); Alpine Blueberry (*V. uliginosum*: S2); and Mountain Sandwort (*Minuartia groenlandica*: S2) (Roland and Smith 1969; Nova Scotia Museum 1997a).

A basic inventory and understanding of coastal barren plant communities is at the heart of all further research and conservation efforts for this system. Therefore, the first question of this research asks:

**1. "Is there a definitive coastal barren plant community common to all sites?"**

By plant community, or community structure, I refer to a) the individual species of vascular plants, macrolichens (foliose and fruticose) and mosses that co-occur; and b) their abundances. Although lichens are not technically plants, they will be included when using such terminology as "plant community and "plant type" for the sake of concision. "Species composition" refers only to the species present, and not to their abundance. When strictly referring to the abundance of species, the term "species abundance" will be used.

Answering this primary question is a crucial first step in being able to ask and answer subsequent questions concerning the relationship between plant communities and environmental factors, as well as correlates of species richness. The primary question of this research is, by necessity, fundamentally exploratory and designed to address both site-level and regional gaps in our knowledge of coastal barren plant communities.

**Environmental factors affecting coastal barren plant communities**

At a basic level, all heathlands are influenced by some type of disturbance regime that permits the persistence of shrub-dominated communities. In many cases, nutrient accumulation is also a limiting environmental factor in the succession of heathlands and

the presence of forest species (Tiffney 1997; Webb 1998; Piessens *et al.* 2006). Nutrient accumulation is itself restricted by environmental conditions, such as high winds, slow decomposition rates in acidic soil, and slow weathering of bedrock, which also inhibits root growth and soil development. Large-scale disturbances such as ice action during glaciation are also known to strip soils and leave behind only thin, coarse till (Nova Scotia Museum 1997a). However, other studies have dismissed the effects of mineral soils and soil parent material on shrubland communities, noting that only the organic layer appears to differ between adjacent areas of shrubland and forest (Eberhardt and Latham 2000; Wibiralske 2002).

Anthropogenic disturbances such as fire are known to impoverish soils by removing litter and humus (Nova Scotia Museum 1997a), impeding the growth of later successional species and favouring post-disturbance woody clonal species. However, the role of fire in the creation and maintenance of heathlands does not appear to be universally consistent. Although there is evidence that the inland barrens of southwestern Nova Scotia have been repeatedly burned (Nova Scotia Museum 1997a), pollen studies from the same region indicate that a shift toward shrub vegetation may have begun prior to European settlement (Nova Scotia Museum 1997a).

In New England, it has been documented that First Nations communities used fire to clear woodland for rotational agriculture and to optimise hunting and gathering conditions (Pyne 1982; Lorimer and White 2003). However, historical records indicate that the majority of New England coastal areas were wooded at the time of European contact in the seventeenth century (McAndrews 1988; Foster and Motzkin 1998; Fuller *et al.* 1998; Russell and Davis 2001). Pre-European open habitats, including coastal

barrens, heathlands, shrublands, and grasslands, were likely limited to smaller areas near settlements, as well as exposed coastal sites that were subject to intense coastal conditions, such as high winds, salt spray and occasional fires (Motzkin and Foster 2002; Latham 2003; Lorimer and White 2003). These chronically disturbed nearshore areas are also most likely to contain long-standing communities of plants that are historically subject to chronic climatic disturbance (Boyce 1954; Dunwiddie 1989). Many of today's uncommon or rare species were restricted to these chronically or intensively disturbed pre-European sites and were also uncommon in pre-European times (Motzkin & Foster 2002).

Records indicate that the area of open habitats increased dramatically during European settlement as a result of logging and agricultural practices, including intensive grazing (Foster 1999; Foster and O'Keefe 2000; Eberhardt *et al.* 2003). The large-scale abandonment of intensive agriculture in New England throughout the nineteenth century and the subsequent afforestation resulted in a decline in open habitat species and a shift in the community types of former agricultural lands (Jenkins 1982; Dunwiddie 1989; Harper 1995). Modern fire suppression may continue to contribute to afforestation, although natural regeneration of mature forest stands can take up to 500 years following moderately severe disturbance (Foster and Motzkin 1998), and up to 1000 years for even primary succession on rock outcrops (Asselin *et al.* 2006). The species able to colonise exposed coastal headlands typified by hard bedrock, slow soil accumulation, and salt spray may be quite limited in number.

In the cool and moist conditions of the North Atlantic region, tree felling also resulted in the formation of moorlands, or bogs (Crawford 2005). This

anthropogenically-driven paludification is highly evident in the bog-barren landscapes of Iceland, Scotland, Norway, and parts of Newfoundland and Nova Scotia, where there is a long history of human settlement. It is thought that a general increase in oceanic conditions beginning 6000 years ago may have initiated forest retreat and bog-barren formation, and that these climatic changes made these regions even more susceptible to human disturbance (Crawford 2005). Altered hydrology may affect the suite of species that can grow in these areas, and changes in soil nutrient levels and pH further discourage the growth of certain species (van Breeman 1995).

Once anthropogenic and/or natural disturbance has removed tree cover, reestablishment of tree seedlings is very difficult in the stressful conditions prevalent in heathlands (Meades 1983; O'Toole 2006). Research in Newfoundland has demonstrated that tree seedling germination is highly unsuccessful under a heavy microshrub cover (Meades 1983). Populations of rare heathland species have been shown to be adversely affected by increased shrub height (Ramsay and Fotherby 2006), and rare coastal barren species may show similar effects with increased vegetation height.

Coastal barrens in Nova Scotia also appear to have minimal tree seedling germination even when surface vegetation is removed (O'Toole 2006), and may be considered an effectively permanent vegetation community in which trees are scarce. Further research has pointed to the positive feedback effects of dominant ericaceous shrubs in indefinitely maintaining the shrubland (Mallik 1993, 1995, 2001; Inderjit and Mallik 1996a, b, 1999; Bradley *et al.* 1997 a, b, 2000). In combination with unfavourable climatic conditions, these factors may greatly encourage persistent shrublands (Mallik 1995).

While insight into biotic effects on plant communities can be addressed by collecting data on the plant communities themselves, investigating abiotic effects on the structure of these plant communities requires a different approach. Relevant environmental factors, such levels of nutrients and organic matter, exposure, substrate depth, distance to coast, substrate moisture conditions, pH, and vegetation height, must be measured at the plot level and combined with species composition and abundance data from question 1 in order to address the second question of this research:

**2. "Which environmental factors are correlated with plant community structure?"**

Measuring the variability of targeted environmental factors in space in time is also crucial to understanding the plant community structure of coastal barrens. Furthermore, these data may provide insights on correlations between rare species and environmental factors that may help inform conservation planning and long-term protection efforts.

**Species richness**

In order to maximise the effectiveness of future conservation efforts directed at this system and its species, it is crucial to go beyond the simple classification of these communities, and to investigate patterns of plant species richness (the number of species per unit area) in coastal barrens. Only by identifying the factors that control species richness can we determine how to protect the full measure of species richness in coastal barrens. A better understanding of site-level species richness may also be useful for prioritising conservation decisions given finite financial resources.

In ecology, richness is often referred to as "diversity," even though "diversity" is technically a measure of both richness and evenness. References to "diversity" in the literature, including those studies addressed below, most often pertain to studies of species richness alone. Discussions on the maintenance of biodiversity, therefore, typically refer to issues concerning the maintenance of $x$ number of different species.

Biodiversity implies the coexistence of multiple species. At the core of the long-standing drive to understand how biodiversity is maintained is the attempt to understand how species coexist. Almost fifty years ago, Hutchinson (1959) asked the now famous question, "Why are there so many kinds of animals?" Today, ecologists must conclude that this question has still not been satisfactorily answered. A list of over 120 hypotheses purporting to explain variations in species richness was produced by Palmer (1994) in a self-admittedly cursory overview of the literature on species richness. When compared to the number of hypotheses proposed to explain other ecological phenomena (on average half a dozen per pattern observed), coexistence studies are something of an aberration (Palmer 1994). Difficulties in refining diversity mechanism hypotheses for species richness can be attributed to perception and naming of observed mechanisms, the scale at which phenomena are observed, and the ambiguous definition of key ecological terms and concepts, particularly "the niche" (Palmer 1994).

The confusion generated by predominantly niche-based models of coexistence has prompted the development of several alternative theories premised on the belief that classical niche models are wrong (Hubbell 2001). However, the view persists that niche differences between plants have simply been overlooked (Silvertown 2004), particularly given the number of environmental gradients that can influence species richness, such as

hydrology, substrate nutrients, substrate depth, exposure, and disturbance. The variability of these environmental gradients must also be considered in space and time.

**Spatial heterogeneity**

Spatial heterogeneity refers to some factor (e.g. a set of environmental conditions) that varies in space. High spatial heterogeneity increases the potential number of niches in a habitat, and could allow species to most effectively compete for resources while avoiding competitive exclusion. The theoretical basis for the maintenance of diversity through spatial heterogeneity is well-established (Tilman 1982; Tilman 1994; Silvertown *et al.* 1999; Chesson 2000). However, most experimental studies to date consider only the response of established communities to mean levels of environmental factors at a particular site, and do not consider the effects of gradients in environmental heterogeneity on diversity (Lundholm 2003). Conclusions concerning the effects of spatial heterogeneity on diversity are also contingent on the scale at which that heterogeneity is studied. At larger scales of study, microenvironmental heterogeneity may be overlooked (Svenning 2001).

Water-availability gradients have been the focus of several studies looking at spatial heterogeneity and plant diversity (Silvertown *et al.* 1999; Lenssen and de Kroon 2005). Silvertown *et al.* (1999) give evidence that plant niches are spatially structured by hydrology, which determines physiological limits to species niches. Lenssen and de Kroon (2005) provide new experimental field evidence that spatial heterogeneity in water supply may segregate niches and thereby promote species richness.

Coastal barren communities have been described as "essentially impoverished habitats, with low nutrient availability and low floral diversity, offering a comparatively small number of niches" (Nova Scotia Museum 1997a, 465). Preliminary field work by Lundholm (2004, unpublished data) suggests that this statement may be unfounded. Lundholm found that substate depths on coastal barrens ranged from 0 to 60 cm in a 1 $m^2$ area. He also noted hydrological conditions that ranged from "exposed areas that likely experience drought in midsummer, to hollows and ponds that may be permanently flooded" (Lundholm 2004, unpublished data). Furthermore, it has been shown that ecologically-similar rock barrens in other regions, such as alvars, are rich in plant diversity, with high species richness found in relatively unproductive areas (Belcher *et al.* 1992; Lundholm and Larson 2003b). More data are needed before conclusions on the contribution of spatial heterogeneity to the plant diversity of coastal barrens can be reached.

**Temporal heterogeneity**

Time can also be considered a factor that species can partition (Gotelli and Graves 1996). Temporal partitioning is a particularly important strategy for sessile organisms that cannot escape competition with neighbours for limited resources (Gotelli and Graves 1996). Various plant functions can be partitioned by time: growth, flowering times and seed dispersal, for example.

Few studies have measured the effects of temporal variability of water supplies on diversity. Data presented in Gitay and Agnew (1989) on the effects of water-table fluctuations on sand dune slacks suggest that species richness increases with increasing

amplitude and frequency of fluctuations in water availability. Bonis *et al.* (1995) examined the vegetation and seed bank dynamics of temporary marshes and found that episodic drought and flooding favoured different species in different years. This temporal variability enabled species with different resource requirements to coexist in the same space, prevented any one species from achieving dominance, and thereby indefinitely delayed competitive exclusion (Bonis *et al.* 1995).

Due to areas of impermeable substrate and to the high topographic variability of coastal barrens, intra-annual temporal moisture variability may play a large role in driving species richness. It has already been shown that regeneration niches for some members of the genus *Vaccinium*, commonly found on coastal barrens, are temporally stratified (Vander Kloet and Hill 2000).

Temporal and spatial heterogeneity of water supplies, as well as the effects of other physical and environmental gradients such as exposure, nutrient levels, elevation, pH, and substrate depth, likely play a role in maintaining diversity on the coastal barrens. The effects of these environmental factors on plant species richness are the focus of the third question of this research:

**3. "How is species richness correlated with environmental factors?"**

Answering this third question will enable us to understand which suite of conditions discourage or promote plant species richness, and how changes in these conditions may affect the richness of coastal barrens plant communities. It is important to note that

species richness is independent of species composition, and that both variables are likely to respond independently to environmental gradients.

**Importance of research**

The identified gaps in our knowledge of the natural history of coastal barrens are problematic for a variety of practical purposes. Effective species-at-risk and protected areas planning requires a basic understanding of the flora of this system, including the number of rare species present, their distribution and local abundance, the plant communities in which they are found, and the environmental conditions with which they are associated. Formal protection of these species and the habitat as a whole cannot properly reflect the needs and sensitivities of species and sites without these kinds of data.

Sound conservation planning for coastal barrens is critical given the current anthropogenic threats to this system. Their proximity to large urban areas, their accessibility and the extremely slow rate of regeneration make coastal barrens sensitive to disturbance by off-road vehicles as well as foot traffic. Increasing development pressures along the coast and accelerated private ownership of coastal barrens raise concerns for long-term connectivity and functionality of the system. Both housing development and off-road vehicles impose major hydrological changes on the landscape, which could have significant effects on plant communities believed to be structured in part by moisture gradients. Anthropogenic and natural disturbance, including the effects of climate change, may have further effects on plant communities that are impossible to predict given our current knowledge of this system. Ultimately, the most successful conservation

efforts will be those that protect both existing diversity and the environmental conditions that drive it.

**Summary of objective and research questions**

The objective of this research is to inform conservation debate in this province. The three central questions of this research are:

1. **Is there a definitive coastal barren vegetation community common to all sites?**
2. **Which environmental factors are correlated with plant community structure?**
3. **How is species richness correlated with environmental factors?**

## Methods

### Coastal barren distribution

In order to compile data on the distribution of coastal barrens, I watched aerial video of the entire coastline of Nova Scotia (Geological Survey of Canada-Atlantic 1987-1993). Coastal barrens were determined to be areas with <10% tree cover that were within 500 m of the coast, and often had exposed bedrock. Based on the distribution maps created from the aerial footage, I consulted 1:10,000 aerial photos to confirm the vegetation and hydrology characteristics of the sites, which further distinguished the sites from bogs. Where possible, ground-truthing of identified coastal barrens was conducted during preliminary field work in 2004 and early 2005.

Coastal barrens appear to be almost exclusively concentrated on the Atlantic Coast of Nova Scotia (Figure 1). Two districts of this shoreline are home to the largest coastal barrens: the Pennant Barrens between Halifax Harbour and St. Margaret's Bay, and part of the Aspotogan Peninsula; and the Canso Barrens in Guysborough County . Both of these coastal barren systems are granitic.

Smaller pockets of coastal barrens occur south of the Pennant Barrens along the south shore to Yarmouth, with a small patch occurring near Digby. Coastal barrens are scarce along the eastern shore between Halifax and Canso. On Cape Breton Island, coastal barrens occur on Isle Madame, north of Louisbourg, Scatarie Island, and in the Cape Breton Highlands from Ingonish to Cape North.

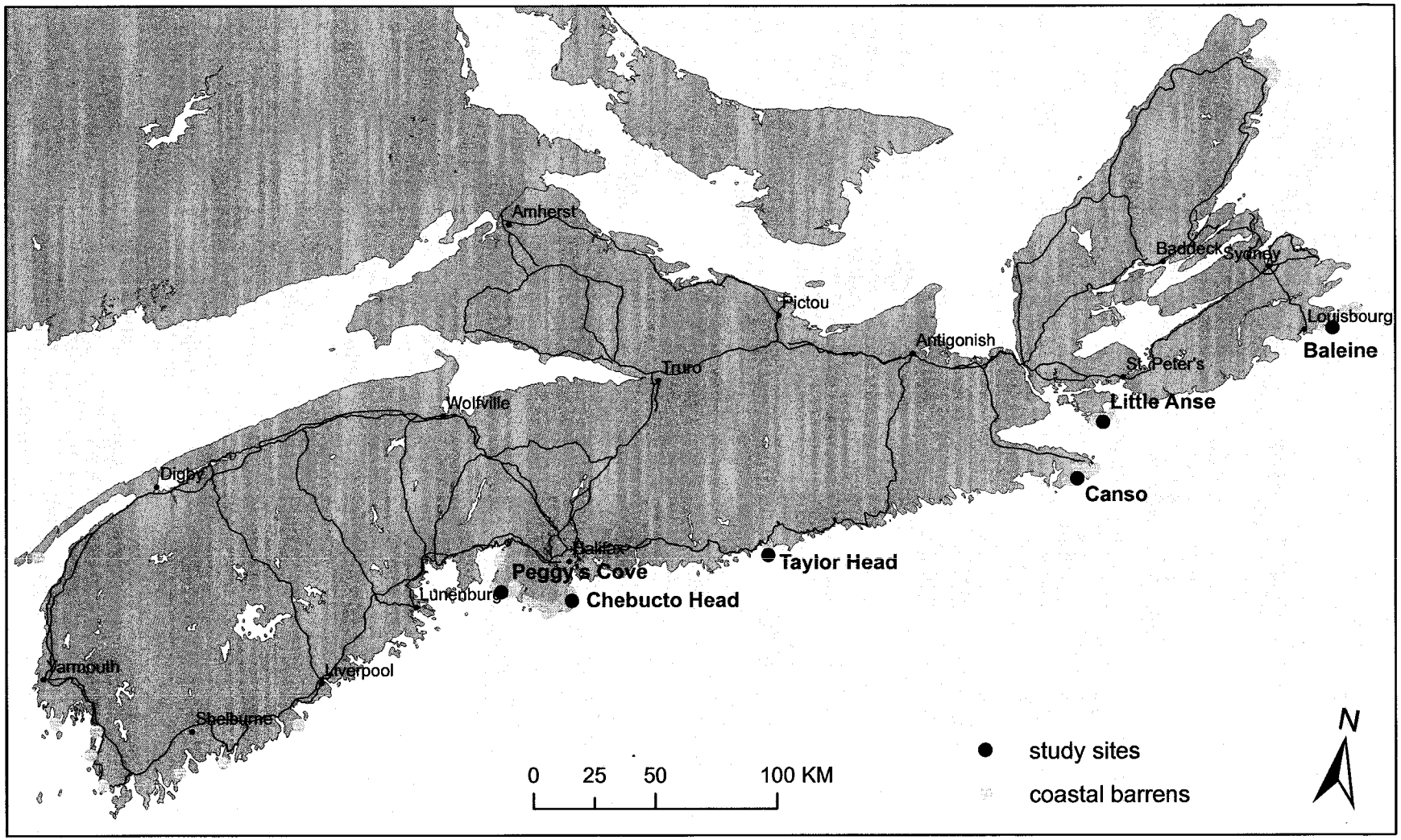



Figure 1. The distribution of coastal barrens in Nova Scotia, and the six selected study sites. Study sites from west to east are: Peggy's Cove, Chebucto Head, Taylor Head, Canso, Little Anse, and Baleine.

**Overview of the region**

Most of the coastal barrens in Nova Scotia fall within the Atlantic Coast Theme Region (Nova Scotia Museum 1997b), typified by coastal forest and exposed headlands. Climatically, the Atlantic Ocean is the dominant influence on this region. The region receives between 1200-1600 mm of precipitation annually, only 15% of which falls as snow. On average, snowfall in the region is less than 200 cm per year, and accumulation is minimal. Snow cover on the coast reaches a maximum of 130 days in parts of Cape Breton, and less on the mainland (Nova Scotia Museum 1997b).

The mean annual temperature range is approximately 15-20 °C on the Atlantic coast, as compared to 20-25 °C in the rest of Nova Scotia (Nova Scotia Museum 1997b). In the winter, mean daily freezing temperatures rarely occur before mid-late December, and usually remain above -5 °C in January. The region has a long frost-free period as well as low evapotranspiration rates. Fog is common, occurring 15-25% of the year (Nova Scotia Museum 1997b).

Soils are strongly affected by climatic conditions, especially the high precipitation and short winters. Geologically, the region contains almost every rock type known to Nova Scotia; however, coastal barrens only occur on the hardest rock types, such as granite, meta-sandstone and basalt (P. Jutras, personal communication, 21 August 2006). Poor drainage in the predominantly acidic soils contributes to the accumulation of a thick layer of surface humus, which decomposes very slowly and contributes to leaching (Nova Scotia Museum 1997b).

**Site selection criteria**

Given the inherent underlying physical and climatic variation in this habitat type and the potential influence of regional species pools, it was necessary to design a multi-site study that would encompass as broad a representation of coastal barrens as possible. In order to facilitate comparisons of plant communities among sites, sites were selected to reflect the ranges of 1) distribution, 2) concentration and 3) size of coastal barrens on the Atlantic coast. Sites were therefore selected to provide a good representation of the north-south distribution gradient, and to reflect the relative concentration of coastal barrens in each region.

Where possible, large protected areas were selected in order to maximise the potential species pool and minimise recent anthropogenic disturbance. A minimum size requirement of 500 m x 500 m was established for sites. Sites were also required to have <10% tree cover.

Based on the above criteria, six coastal barrens sites were selected for this study (Figure 1, Appendix E). They extended from Baleine, north of Louisbourg, to Peggy's Cove. Two sites, Chebucto Head and Peggy's Cove, were selected in the Pennant Barrens district to reflect the significant concentration of coastal barrens in that region of the province.

**Site-specific descriptions**

The following site-specific descriptions were produced during the selection process in April 2005. They are qualitative and meant to provide the reader with a brief introduction to the research sites. Sites are discussed from west to east.

**Peggy's Cove**

The Peggy's Cove coastal barren stretches five kilometres from West Dover to Indian Harbour, and extends approximately 4 km inland. The area is visually striking: large treeless hills with dramatic granitic outcrops and massive erratics dominate the landscape. In autumn, the entire area is a vibrant red, due predominantly to the conspicuous autumn colours of huckleberries (*G. baccata*, *G. dumosa*). The entire coastal barren complex is Crown land with no existing level of protection.

The field site is a section of the coastal barren approximately 1.5 km east of Peggy's Cove. This area is representative of much of the surrounding coastal barren complex, although shoreline effects here may be more pronounced than barren areas farther inland. Topography is extremely variable, alternating between high exposed ledges with only lichens (*Umbilicaria* spp.) and low-lying areas of *Sphagnum* bog. Standing water is persistent in small pools in the spring and autumn, and to a lesser degree in summer. Snow cover is light in the winter, although in February 2006 I observed certain areas that were covered by drifts >1 m. Soils appear siliceous and of variable depth.

Dominant vegetation includes *G. baccata, G. dumosa*, *C. conradii*, *J. communis,* and *K. angustifolia*. *Cladonia* species are also abundant, especially *Cladonia boryii* and *C. terrae-novae*. Trees (predominantly *P. rubens*) are scarce and occur in small copses, and *P. glauca* can be found growing along the shoreline. White pine (*Pinus glauca*) is also found at the site, although the climatic conditions are so stressful that it grows prone on the rock, almost like a creeping shrub.

The area is well-used by hikers, dog-walkers and rock-climbers, and numerous footpaths criss-cross the site. These footpaths grow wider during wet seasons as site visitors attempt to skirt standing water, and it appears that vegetation is slow to recover from even moderate foot traffic. ATV tracks are visible in some places, but it is difficult to determine how recently they were created and whether they are still used. Areas of the coastal barren north of Highway 133 are certainly still used by ATVs.

**Chebucto Head**

Chebucto Head is approximately 40 km southeast of Halifax on the Chebucto Peninsula. It is a section of coastal barrens contained within the Duncan's Cove Nature Reserve. The area is very popular with hikers and sight-seers.

Chebucto Head forms part of the Pennant Barrens system, which also includes the coastal barrens around Peggy's Cove. This system is typified by conspicuous granite outcrops and large erratics, as well as strong elevation gradients. Microtopography is extremely variable, and is less evenly patterned than at Baleine, for example. Standing water remains in small troughs throughout the spring and autumn.

Pockets of bog are located between granite ridges and are home to numerous hydrophilic species, including Pitcher Plant (*Sarracenia purpurea*), Round-leaved Sundew (*Drosera rotundifolia*) and numerous *Sphagnum* species. On exposed ridges with very shallow soil, Common Juniper (*Juniperus communis*) is abundant, as are *E. nigrum*, *C. conradii* and Wintergreen (*Gaultheria procumbens*). Shrub communities on slopes and in depressions by exposed granite are dominated by *G. baccata* and *K. angustifolia*. Copses of trees are very rare and occur predominantly in more sheltered

stream valleys. Tree species on the site include *P. glauca* and Green Alder (*Alnus viridis).* The site is also known to contain *E. eamesii* (S2) and *Vaccinium uliginosum* (S2).

The area experiences extremely localised weather phenomena. The coast may be foggy, windy and cold when nearby Halifax is mild and sunny. Wave action and wind intensity are responsible for drifting spray, and slopes facing the coastline likely receive more saltwater than areas sheltered behind inland ridges. Despite the spray, areas near the shoreline are vegetated, and most exposed faces are inhabited by crustose and foliose lichen species. Disturbances to the area include braided hiking trails and, further inland, ATV tracks.

**Taylor Head**

Taylor Head Provincial Park is a narrow peninsula on the eastern shore, approximately 100 km from Halifax. The park officially protects 16 km of coastline, as well as spruce forest, beach, meadows, and coastal barrens. The peninsula is dominated by spruce and balsam forest, which frequently intrudes into the small openings of coastal barrens as small, dense copses of stunted trees.

The coastal barren exhibits less variation in topography than Chebucto Head or Peggy's Cove, sloping gently upwards inland. Immediately adjacent to the coast, large areas are dominated by exposed meta-greywacke, although areas a short distance inland have little in the way of exposed bedrock. Mats of *E. nigrum* cover the hummocky microtopography, and large areas of boggy depressions are dominated by *Trichophorum*

*caespitosum.* Other bog-barrens species such *K. angustifolia* and *R. groenlandicum* are common.

Parts of the park were once settled and farmed, but these sites are largely on the eastern side of the park and are now characterised by revegetated meadows (Nova Scotia Provincial Parks 2006). There is no known evidence of historical human inhabitation or disturbance in the coastal barren areas. The provincial park is popular with hikers, but the well-defined trail keeps off-trail impacts to a minimum.

**Canso**

The Canso Coastal Barrens Wilderness Area is located near the mouth of Chedabucto Bay. This 3000 hectare area contains the largest protected coastal barren site in Nova Scotia. Coastal barrens are also prevalent on nearshore islands of the area.

The slope of the land is variable depending on location within the wilderness area and can be quite steep near streams, but is generally moderate over much of the site. Elevation exceeds 200 m along some large inland ridges. Microtopography is not easily discernable given the dense shrub cover, but the substrate is uneven and characterised by hummocks and troughs. Standing water on the site was not apparent. Infiltration of runoff may be high due to a relatively thick organic layer. The bedrock is granitic and weathering is very slow.

Vegetation at the site is dominated by ericaceous shrub species, such as Black Huckleberry (*Gaylussacia baccata*), *K. angustifolia* and *C. conradii.* Cinnamon Fern (*Osmunda cinnamomea*) is common in low-lying areas closer to the coast. Copses of balsam fir (*Abies balsamea*) grow to heights in excess of 5 m within 200 m of the coastline, and are usually densely covered with *Usnea* spp.

Very little data exist on the historical uses of this study site. According to the Nova Scotia Theme Regions Guide (1997b), "Canso" is derived from the Mi'kmaq "Kamsok," or "opposite the lofty cliffs," indicating that exposed rock outcrops have been a long-term feature of the landscape. Reports from 1912 make reference to the exposed rock and erratics that typify the wilderness area, as well as to very thin soils (Nova Scotia Museum 1997b). Local residents report that parts of the coastal barrens burned decades ago, but there is no visible evidence of recent fire in the immediate study area. Several well-established ATV trails exist on the site, and a network of severely braided trails criss-cross through a boggy access point. Other disturbances include semi-permanent beach shelters, small snares and hunting.

**Little Anse**

Little Anse is the closest town to the actual field site, Heath Head, which is located at the southernmost tip of Petit-de-Grat, Isle Madame, on Cape Breton Island. Isle Madame was settled by Europeans at the same time as Louisbourg, and has had a sustained human presence ever since. In the age of tall ships, Isle Madame was an important commercial trading and boat building centre and much more heavily populated than at present time.

The field site, Heath Head, is privately owned. The owner has plans to develop a residential building on the site, but at present there are no structures on the land with the exception of an old duck hunting shed. The site is easily accessible by a dirt track that is used by ATVs and pick-up trucks.

The coastal barren displays the familiar hummock and trough topography, although the macrotopography of the site is rolling and moderate. A small, sluggish

stream cuts across the site approximately 150 m from the coastline, and nearby is a small copse of *P. glauca*. Standing water was only observed in very small and infrequent pools. This site has very little exposed rock, and soils appear to be shallow.

Dominant plants include *E. nigrum* and Lowbush Blueberry (*Vaccinium angustifolium*). A large section of the coastal barren, close to the coast, is known to have burned approximately five years ago in a human-set fire. The fire extended approximately 150 m inland and burned rapidly, according to local witnesses (C. David, personal communication, 27 May 2005). The vegetation of this newly-burned section is now dominated by *M. canadense*, Mountain Cranberry (*Vaccinium vitis-idaea*), Three-leaved Cinquefoil (*Sibbaldiopsis tridentata*), and Poverty Oat-grass (*Danthonia spicata*). *O. cinnamomea* is common by the small stream.

Parts of the site have been used as pastureland in the past. ATV use of the site appears infrequent but many different sets of tracks are discernable.

**Baleine**

Baleine lies approximately 10 km northeast of the town of Louisbourg. The area was the site of the first permanent European settlement on Cape Breton Island in 1629, and has been occupied intermittently and fished continuously since that time. Currently, several houses are located in the harbour and fishing continues on a seasonal basis. Most of its coastal barrens are on Crown land.

The field site is part of a much larger contiguous barren-bog complex and is accessible by a half hour walk across a stone causeway. Several ridges and knolls provide topographic variety, but the majority of the land is low-lying, increasing gradually in slope inland.

The microtopography of the site is extremely variable. Hummocks and troughs >1 m high and deep, respectively, form a regular interlocking mosaic in low-lying areas. Hummocks were still partly frozen in mid-April, and streams course through connected troughs in the spring melt. Many troughs held standing water until July. Large shallow ponds of standing water occur 500 m inland and retain water throughout the summer.

Vegetation is predominantly ericaceous and low-growing. Bog species, such as Cloudberry (*Rubus chamaemorus*), *E. nigrum*, Labrador Tea (*Rhodedendron groenlandicum*), and Bog Rosemary (*Andromeda polifolia*) are abundant. Tree cover in the area is restricted to inland hilltops, where stunted and bent growth forms of *Picea rubens* (Red Spruce) and *Abies balsamea* (Balsam Fir) reflect the severity of wind stress. *Picea glauca* occurs in small copses in lowland areas, but it is nearly prostrate and rarely exceeds more than a metre in height.

Debris, including logs, lobster pots and plastic containers, are found up to 200 m inland, indicating that wave, wind and ice action are extremely powerful along the coast. The site is almost always windy, cool and moist. Fog is prevalent at the site, even when neighbouring coastal and inland conditions are sunny and mild.

Although the area is remote and moderately difficult to access, ATV damage is obvious in places, especially where the ground is soft and retains tire gouges. The patchy wet conditions also encourage braided trails. Historical documents do not point to sizeable or intense anthropogenic disturbance since the time of European settlement, although it is possible that limited tree felling may have occurred. The area is generally unfit for pasturing. No evidence suggests that the site has changed markedly since settlement. Accounts from 1672 describe the land as being "worth very little," and

reports from the1750s refer to the land at Baleine as being entirely deserted, treeless, covered with rocks, and having soft and peaty ground. The ground was said to be so wet as to be impassable to men on foot (Louisbourg Institute of Cape Breton University 2006).

**Sampling design**

Using ArcGIS 9.1 (Environmental Systems Research Institute 2005), I overlayed 1:10,000 topographical maps on 1:10,000 aerial photos (1998, 2000, 2002, 2003). I divided each site into 500 x 500 m grids, consisting of fifty 500 m x 10 m transects. The transects were oriented perpendicular to the coastline, which was also roughly perpendicular to the most variable elevation gradient at each site. I then used a random number generator to select one transect at each site, and randomly generated 20 UTMs within each selected transect. These UTMs were downloaded onto the handheld Garmin eTrex Legend C GPS Unit (Olathe KS 2004).

In the field, each UTM was located with the handheld Garmin GPS unit. Because the handheld GPS unit has an approximate accuracy of 5+ m in the coastal barrens, the downloaded UTMs were not exactly located. Rather, they were approached using the "find waypoint" function, and determined to be reached when this feature ceased to direct me further. Once it was confirmed that the immediate area was both accessible and not traversed by ATV or foot trails, I established the southwest corner of the plot as the place that I was standing. I oriented the 1 x 1 m plot along a north-south axis and marked each corner with a stainless steel rod and an aluminium tag. In the event that a plot contained insufficient substrate for the rods, corners were marked with surveyor's paint. All plots

were photographed along the north-south axis and numbered 1 to 20, beginning with plot 1 at the coast and increasing in number inland.

Plot size for this research was determined based on preliminary sampling work at Chebucto Head in April 2005. Although it has been shown that species richness increases with sampling area (Rosenzweig 1995; Gotelli and Graves 1996), it was determined that increasing quadrat size from 0.1 $m^2$ to 25 $m^2$ did not produce a correspondingly large increase in species richness (Oberndorfer 2005, unpublished data). Therefore, representative sampling could be more accurately and more expediently accomplished using a smaller 1 x 1 m quadrat size, which is the best quadrat size for non-treed vegetation (Krebs 1999).

**Dependent variables**

Each 1 x 1 m plot was subdivided into twenty-five 20 x 20 cm subplots using a portable quadrat frame, where each subplot was 4% of the total quadrat area. Vegetation sampling was conducted using the point-intersect method (Krebs 1999): a thin metal rod was inserted into the ground at the intersection of each subplot corner. All vegetation touching the rod at that point was recorded. All species of vascular plants, mosses and macrolichens (fruticose and foliose) were noted at each of the 36 intersect points per plot. Crustose lichens, liverworts and hornworts were not surveyed due to time constraints. Point counts were subsequently used to generate plot-level summaries of vegetation structure and species richness.

Species rarity was assessed using the provincial ranking system of the Atlantic Canada Conservation Data Centre (2006). Species ranked S1 (extremely rare: five or

fewer occurrences in NS) or S2 (rare: six to twenty occurrences in NS) were considered rare in this study. The subsequent use of the term "common species" refers to the frequency of a species' overall occurrence (total number of times it was recorded touching the 2 mm diameter rod). Therefore, a list of the ten most common species among sites refers to the 10 most frequently sampled species over all sites.

**Independent variables**

We estimated the percentage cover of exposed rock in each plot using the 1x1 m quadrat as a guideline.

Average vegetation height was calculated by averaging ten random measurements of vegetation height throughout the plot, in all plots in August 2005.

Substrate depth was calculated by inserting a thin metal rod (2 mm diameter) into the substrate in four corners of the plot until it reached bedrock. Substrate depth was measured to the nearest 0.10 cm, to a maximum of 120 cm. In plots where substrate depth exceeded 120 cm, such as in *Sphagnum* bog plots, we recorded a depth of >120 cm. The four readings were averaged to determine mean substrate depth of the plot. Measurements were taken at the plot corners in order to later generate data on the substrate depth range (maximum substrate depth – minimum substrate depth) and substrate depth CV (standard deviation of plot corner substrate depths/average of plot corner substrate depths) of the plot. "Substrate" is used in lieu of "soil" to include non-soil materials in which coastal barren communities are anchored, such as peat.

Relative exposure was calculated using tatter flags. Tatter flags are extensively used in forestry research to measure wind speed and exposure (Tombleson 1982;

Tombleson *et al.* 1982). Mass loss is known to increase with high wind speeds and wet conditions (Rutter 1965). We used dyed green 3"x 5" rectangles of medium-weight cotton, fitted with a reinforced grommet. Each tatter flag was weighed on a balance with one-thousandth gram accuracy and loosely attached to the southwest corner of each plot at average vegetation height using a thin aluminium wire. Tatter flags were collected after approximately two months in the field, dried, and reweighed in order to record mass lost. Percentage of total mass lost was calculated using the original weight of each tatter flag, and was standardised using the number of days each flag was in the field.

Distance to coast and elevation were measured to sub-meter accuracy using a Leica Geosystems GS20 rover unit and a Leica Geosystems System 500GPS base station (Leica 2003). All distance and elevation readings were taken at the southwest corner of each plot.

Moisture readings were taken at each plot corner on five separate sampling dates throughout the field season. We used the HH2 Moisture Meter with the ML2x Theta Probe (Delta T Devices Ltd. 2004) to obtain substrate moisture readings in mVs. On each occasion, moisture was sampled three times consecutively at each plot corner. All mV readings were converted to volumetric substrate moisture content using calibration equations specific to each site's substrate type.

In cases where substrate depth at a plot corner was less than 5 cm (the minimum depth required for using the moisture probe), gravimetric sampling was employed. Vials were preweighed, weighed with wet substrate, and then weighed again after 48 hours in a drying oven. Water weight per vial (wet substrate+vial – dry substrate+vial) and dry substrate weight (dry substrate+vial – vial weight) were used to calculate substrate

moisture content (water weight/dry substrate weight). This gravimetric value was then converted to volumetric substrate moisture content using linear regression, and an equation for a line of best fit was developed for a typical substrate for each site.

The subplot volumetric substrate moisture contents were used to calculate different plot-level measures of temporal and spatial moisture variability according to the following calculations:

1. Temporal mean:

i. mean volumetric substrate moisture content values from all corners of a single plot for each sampling date (n = 5 dates)

ii. mean of the 5 means from i.

2. Temporal range:

i. mean volumetric substrate moisture content values from all corners of a single plot for each sampling date (n = 5 dates)

ii. difference between the max. and min. volumetric substrate moisture content values (the average plot volumetric substrate moisture content from the wettest sampling date – the average plot volumetric substrate moisture content from the driest sampling date).

3. Temporal CV

i. mean volumetric substrate moisture content values from all corners of a single plot for each sampling date (n = 5 dates)

ii. SD of 5 average volumetric substrate moisture content values from i.

iii. ii. divided by i.

4 Maximum spatial volumetric substrate moisture content

i. mean volumetric substrate moisture content values from all corners of a single plot for each sampling date (n = 5 dates)

ii. maximum plot-level volumetric substrate moisture content value from i.

5. Minimum spatial volumetric substrate moisture content

i. mean volumetric substrate moisture content values from all corners of a single plot for each sampling date (n = 5 dates)

ii. minimum plot-level volumetric substrate moisture content value from i.

6. Maximum spatial range

i. range between the highest corner volumetric substrate moisture content value and the lowest corner volumetric substrate moisture content value (wettest corner-driest corner), (n = 5 dates)

ii. greatest range from i.

7. Spatial CV

i. CV using the volumetric substrate moisture content corner data (STDEV 4 corners/average of 4 corners), (n = 5 dates)

ii. mean of the 5 CVs from i.

Four 500 mL substrate samples were collected from each plot. The four samples were then pooled and plot-level substrate samples were sent to the Nova Scotia Agricultural College for analysis of pH, levels of organic matter, P, K, Ca, Mg, Na, S, Fe, Mn, Cu, Z. B, N, and CEC.

**Statistical analyses**

Correspondence analysis (CA)

In order to address Question 1 (Is there a definitive coastal barren vegetation community common to all sites?), I performed correspondence analyses (CA) (CANOCO ver. 3.1). A CA maximises the correspondence between sample scores and species scores (Legendre and Legendre 1998). The relatedness of plots is determined based on the species in those plots, and the abundance of those species. Plots that share similar species composition and similar abundances are plotted closer together in space, and plots dissimilar in these regards are plotted farther away from each other. A CA does this by condensing the multivariate species data into fewer axes that take into account correlations between abundances of different species, thereby simplifying the interpretation of the multivariate patterns (Legendre and Legendre 1998). Only the first four axes are displayed, and only axes one and two typically have eigenvalues large

enough (eigenvalue >0.4) to be considered significant (Gotelli and Graves 1996). An eigenvalue is associated with each axis (also called an eigenvector), and is interpretable as a correlation coefficient between species and samples vectors (Gotelli and Graves 1996). Outliers are a common feature of almost any correspondence analysis, and while the decision to remove outliers is typically at the discretion of the analyst, they are generally defined as data points that are ≥2 or more SD units away from any other data point.

Correspondence analyses (and all subsequent analyses relating to community structure: questions 1 and 2) were performed on the entire data set (all species) and on each individual plant type (vascular plants, mosses, lichens). The data were analysed according to plant type in order to see whether any one plant type had an inordinately strong effect on resolving site differences. If a plant type was found to have a strong influence on resolving site differences, it would mean that site-level differences in the community structure of other plant types could be overlooked. Therefore, these plant type-based analyses were used to improve the resolution at which differences in community structure could be discussed. Similarly, species data were transformed to a presence-absence format for additional analyses in questions 1 and 2 to remove the potential effects of rare or extremely common species.

Multi-dimensional scaling (MDS)

The CA results were confirmed by running multi-dimensional scaling with the same data set (PRIMER 6 Beta), which also confirms that the CA results were robust to assumptions of univariate species distributions; and also by running a detrended

correspondence analysis (DCA) (CANOCO ver. 3.1), which removes the arch effect commonly seen in a CA (Gotelli and Graves 1996). However, the validity of this analysis has been questioned by some (Gotelli and Graves 1996) and it was therefore not used as the primary statistical technique in this analysis.

Analysis of similarities (ANOSIM)

The ANOSIM test calculates similarities in community structure between sites, and compares this with the similarities in community structure found between plots at each individual site (Clarke and Warwick 2001; Clarke and Gorley 2005; Lundholm and Marlin 2006). A random shuffling of the site membership of each individual plot (10,000 permutations) produced the test statistic (R). A significance value was derived by comparing a null distribution to the distribution of R values (Lundholm and Marlin 2006). R values close to 1 indicate dissimilarities between sites, and R values close to 0 indicate large similarities between sites. Bray-Curtis similarities were used as a similarity matrix for the permutation analysis. I calculated separation effect size (R) between sites using ANOSIM procedures in Primer v. 6 (Clarke and Gorley 2005). This program was also used to perform tests of statistical significance on the effect size.

Canonical correspondence analysis (CCA)

To answer the second question (Which environmental factors are correlated with plant community structure?), I performed canonical correspondence analyses (CCA) (CANOCO ver. 3.1). A CCA is a widely used method of direct gradient analysis that creates axes using environmental variable data and plots species along these axes in a

way that best illustrates the species' response curve (ter Braak 1986). Most of the variation in the species data is usually explained by the first two axes. In a canonical correspondence analysis graph, the relative length of the environmental variable arrows indicates the importance of the environmental variables in differentiating plots. Monte Carlo tests were performed for all CCAs with 449 permutations under a reduced model

In order to quantify the relative sizes of the effects of site, environmental and species variation among plots, a partial canonical correspondence analysis was performed (CANOCO ver. 3.1). This analysis factors out the effect of a particular environmental variable on separating out species in the ordination. In this case, site was included as a variable and factored out to see if spatial autocorrelation was largely responsible for how the species loaded on the axes (ter Braak 1988).

Principal components analysis (PCA) and linear regression

In order to determine correlations between environmental variables and species richness, I performed a Principal Components Analysis (PCA) on transformed (to normal distribution) environmental variables, and linear stepwise regression with species data and the PCA axes representing environmental variables (CANOCO ver. 3.1). A PCA is a rotation of the original data matrix that projects samples onto new sets of linear axes. These axes are combinations of the original environmental variables, and are called components or factors. The first component contains as much of the original variance as possible. Each axis will explain variation in the data that is uncorrelated with other axes (Legendre and Legendre 1998). All factors with eigenvalues >1 were considered

significant and were retained. A VARIMAX rotation was used to aid in the interpretation of the components.

I then performed a linear regression of PCA factors vs. species richness data to look at correlations between species richness and composites of environmental variables. Both backward and forward stepwise selection were used to ensure that the final model was not dependent on the order of terms entering the model. Exclusion of significant outliers was an important consideration in this analysis as a PCA is sensitive to outliers. A correlation matrix was used to standardise environmental variables in different units and magnitudes (Legendre and Legendre 1998). Regression assumptions were tested by assessing the normality and homogeneity of the residuals of the final model.

## Results

### Overview of site-level species data

Across all six sites, I found a total of 176 species of vascular plants, macrolichens (fruticose and foliose) and mosses (Appendices A-C). Although liverworts and hornworts were not sampled, one liverwort species (*Ptilidium pulcherrimum*) was mistaken for a moss and was included in the total species list. Two crustose lichen species (*Arctoparmelia centrifuga* and *Ochrolechia frigida)*, thought to be foliose lichens, were also included.

Of these 176 species, ferns and fern allies accounted for six species, the most common being *O. cinnamomea.* The Cyperaceae were represented by 14 species, 9 of which were *Carex* species. *Carex nigra* and *T. caespitosum* were the most abundant species in this family. Five grass species were found, none of which were very abundant. Of these five species, *Calamagrostis pickeringii* was the most abundant grass on the coastal barrens.

Other vascular plants accounted for 80 species, nearly half of the total number of species recorded. This group was dominated by ericaceous plants, and the families Asteraceae and Rosaceae were also strongly represented in terms of the number of species present from these families. Forty-three species of lichens were recorded, and *Cladonia* species were by far the most commonly encountered. Mosses were represented by 28 species, the majority of which were in the genus *Sphagnum.*

## 1) Is there a definitive coastal barren plant community common to all sites?

### Common species

The most frequently recorded species across all sites was *E. nigrum* (n = 1,321/of 12,225 intersect points, or 10.8% of all plants and lichens recorded) (Table 1). Despite its abundance, *E. nigrum* was not recorded in any plots at Canso, although it was noted in other areas of this site. The second most common species on the coastal barrens was *J. communis*, with 888 occurrences. Third most common was *K. angustifolia*, with 824 occurrences. The most common macrolichen species was *C. terrae-novae* (666 occurrences). The most commonn moss species was *Pleurozium schreberi* (169 occurrences). The top ten species by measure of point intersect occurrence are listed below (Table 1):

Table 1. The ten most common species found across all six field sites, including their rate of occurrence (number of times recorded in point intersect surveying), and the percentage of total individual recorded plants represented by those species.

| **Species** | **Family** | **Point Intersect Occurrence** | **% total (out of 12,225)** | **# sites where found** |
|---|---|---|---|---|
| *Empetrum nigrum* | Empetraceae | 1321 | 10.8 | 5 |
| *Juniperus communis* | Cupressaceae | 888 | 7.3 | 6 |
| *Kalmia angustifolia* | Ericaceae | 824 | 6.7 | 6 |
| *Cladonia terrae-novae* | Cladoniaceae | 666 | 5.4 | 6 |
| *Gaylussacia baccata* | Ericaceae | 641 | 5.2 | 4 |
| *Vaccinium angustifolium* | Ericaceae | 575 | 4.7 | 6 |
| *Vaccinium vitis-idaea* | Ericaceae | 333 | 2.7 | 6 |
| *Corema conradii* | Empetraceae | 303 | 2.5 | 3 |
| *Rhodedendron groenlandicum* | Ericaceae | 297 | 2.4 | 6 |
| *Osmunda cinnamomea* | Osmundaceae | 285 | 2.3 | 5 |

### Inter-site community commonalities

Of a total of 176 species, only 15 species (8.5% of the total species pool) were found at all six sites: 11 vascular species (*Photinia melanocarpa*, *C. canadensis*, *G.*

*procumbens*, *J. communis*, *K. angustifolia*, *R. groenlandicum*, *M. canadense*, *Morella pensylvanica*, *Trientalis borealis*, *V. angustifolium*, and *V. vitis-idaea*); 3 macrolichens (*Cladonia mitis*, *C. terrae-novae* and *Hypogymnia physodes*); and one moss (*P. schreberi*). An additional 24 species were commonly found at 5 sites.

Canso was also the site containing the highest number of species unique to one site, with 21 species found only at Canso (Table 2). Of these 21 unique species, 11 were vascular, 9 were macrolichens, and one was a moss. Baleine had the highest number of unique vascular species, with 13. Chebucto had only one unique macrolichen, and no unique mosses. Peggy's Cove had the highest number of unique moss species, with four in total

Table 2. Number and distribution of unique species (species found only at one site), by plant type. BA=Baleine; CA-Canso; CH=Chebucto Head; LI=Little Anse; PE=Peggy's Cove; TA=Taylor Head.

| | **BA** | **CA** | **CH** | **LI** | **PE** | **TA** |
|---|---|---|---|---|---|---|
| # unique vascular | 13 | 11 | 7 | 4 | 9 | 1 |
| # unique lichens | 1 | 9 | 1 | 2 | 3 | 1 |
| # unique mosses | 1 | 1 | 0 | 2 | 4 | 3 |
| TOTAL | 15 | 21 | 8 | 6 | 12 | 2 |

**Rare species**

Eleven provincially rare species (S1/S2) were recorded across the six sites (Table 3). At least one rare species was found at each site. Six of the eleven rare species are vascular plants, and five are mosses. Two of the rare species, *Sphagnum flavicomans and S. imbricatum*, were found at multiple sites (3 sites and 5 sites, respectively), but the remaining nine species were found at one site each.

Baleine was richest in rare species with seven rare species recorded, four of which were vascular species. Peggy's Cove and Chebucto Head each had three rare species,

Little Anse contained two rare species, and Canso and Taylor Head each had one rare species. There is currently no data available on the abundance of macrolichen species in Nova Scotia. It is also likely that moss species in the Maritimes are understudied and underreported, and therefore the SRANKS are potentially not reflective of the true status of these species. For example, *S. flavicomans and S. imbricatum* are listed as rare, but were not uncommon at five of the six sites.

While most rare species were both restricted to a single site and were low in abundance at that site, some rare species appeared to be locally common. Although *E. eamesii* was recorded only in the plots at Chebucto Head, it was observed 29 times during sampling. I have observed it to be quite widespread at rock outcrop edges near the coast. *Carex rariflora* was observed only at Baleine, but was noted 18 times during sampling and appeared to be locally abundant in nearshore crowberry hummocks.

In general, rare species were found in communities of common plants. Most of the rare vascular species were associated with such typical dominants as *E. nigrum, J. communis, K. angustifolia,* and *V. angustifolium.* Two rare species, *C. rariflora* and *Vaccinium boreale,* occur with more hydrophilic species, such as *T. caespitosum,* whereas *Carex tenera* occurs more commonly with low-ground cover such as *S. tridentata* and *V. vitis-idaea.* At Chebucto Head, *E. eamesii* was typically found with common species, including *C. conradii, J. communis* and *G. baccata.* However, in plot CH-01, *E. eamesii* was found growing in a different plant community, of which *J. horizontalis* was the dominant species. *E. eamesii* has elsewhere been observed growing with more common species, such as *C. conradii* and *V. angustifolium.* It appears to grow well at the interface of exposed bedrock and vegetation.

It should be noted that several of the rare species were observed to be present at sites even though they were not captured in plot-level sampling efforts. *E. eamesii* appears to be locally common at Peggy's Cove. As previously mentioned, several of the rare mosses occur commonly at a number of sites where they were not recorded. For example, *Racomitrium* species have been observed at Peggy's Cove. Finally, several rare species known to be present on coastal barrens did not appear in the plots. *Minuartia groenlandica* (S2) has been recorded at Peggy's Cove, and *Vaccinium uliginosum* (S2) is found at Chebucto Head.

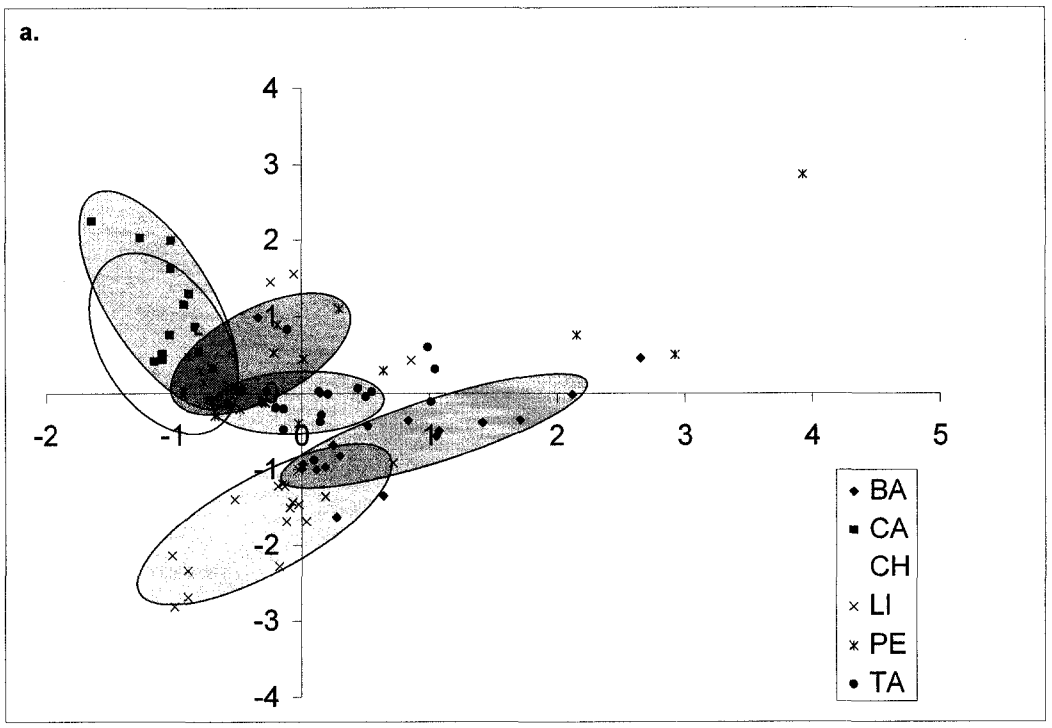
Table 3. Rare species found on the coastal barrens, including their family and SRANK. S1=extremely rare: five or fewer occurrences; S2=rare: six to twenty occurrences; S3=uncommon or with restricted range, even if locally abundant at some locations: 21-100 occurrences (Atlantic Canada Conservation Data Centre 2006).

| **Species** | **Family** | **SRANK** | **BA** | **CA** | **CH** | **LI** | **PE** | **TA** | **#sites present** | **# records** |
|---|---|---|---|---|---|---|---|---|---|---|
| *Solidago multiradiata* | Asteraceae | S1S2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Empetrum eamesii* | Empetraceae | S2S3 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 29 |
| *Prenanthes nana* | Asteraceae | S2? | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 10 |
| *Vaccinium boreale* | Ericaceae | S2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Carex rariflora* | Cyperaceae | S1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 18 |
| *Carex tenera* | Cyperaceae | S1S2 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Racomitrium canescens* | Grimmiaceae | S2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Racomitrium lanuginosum* | Grimmiaceae | S2S3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Sphagnum angustifolium* | Sphagnaceae | S1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 11 |
| *Sphagnum flavicomans* | Sphagnaceae | S2 | 1 | 0 | 1 | 0 | 1 | 0 | 3 | 37 |
| *Sphagnum imbricatum* | Sphagnaceae | S2 | 1 | 1 | 1 | 0 | 1 | 1 | 5 | 33 |
| **TOTAL # rare species** | | | **7** | **1** | **3** | **2** | **3** | **1** | | |

## Correspondence Analysis

### All plots

A correspondence analysis using all plot data produced a graph with 10 large outliers on all axes. These outlying plots on axis 1 were BA-01, BA-02, CA-01, CA-04, CA-10, CA-11, CH-01, PE-07, PE-20, and TA-01. All of these plots contained unique species or generally uncommon species in large quantities that did not typically reflect the species composition in most plots. BA-01 contained the only specimen of *Iris setosa* found in the plots, as well as a large population of *Festuca rubra.* BA-02 contained a large quantity of *Carex palustris* and a single occurrence of a *Juncus* species. CA-01 was dominated by grass species, such as *Poa palustris* and *F. rubra,* and also contained the uncommon *Rosa carolina.* CA-04 was unusual in having a large population of *Chamerion angustifolim,* the only occurrence of *Dryopteris carthusiana,* and a large population of *P. palustris.* CA-10 was one of three forest plots dominated by *Abies balsamea*, which supported a population of *Usnea filipendula* not found in any other plot in the study. CA-11 was likewise a forest plot dominated by *A. balsamea,* also contained several unique tree lichen species, and had a ground layer dominated by *Linnaea borealis.* CH-01 was unusual is having very few species save the dominant *J. horizontalis* and *E. easmesii.* PE-07 was entirely devoid of vegetation except for two unique rock lichens, *Lasallia papulosa* and *Melanelia stygia.* PE-20 was dominated by *Ilex glabra* and contained the *Sphagnum russowii*, which was found only in two plots at Peggy's Cove . Finally, TA-01 was largely devoid of vegetation except for a large population of *Plantago maritima.* These plots were iteratively excluded from subsequent correspondence analyses dealing with all plot data.



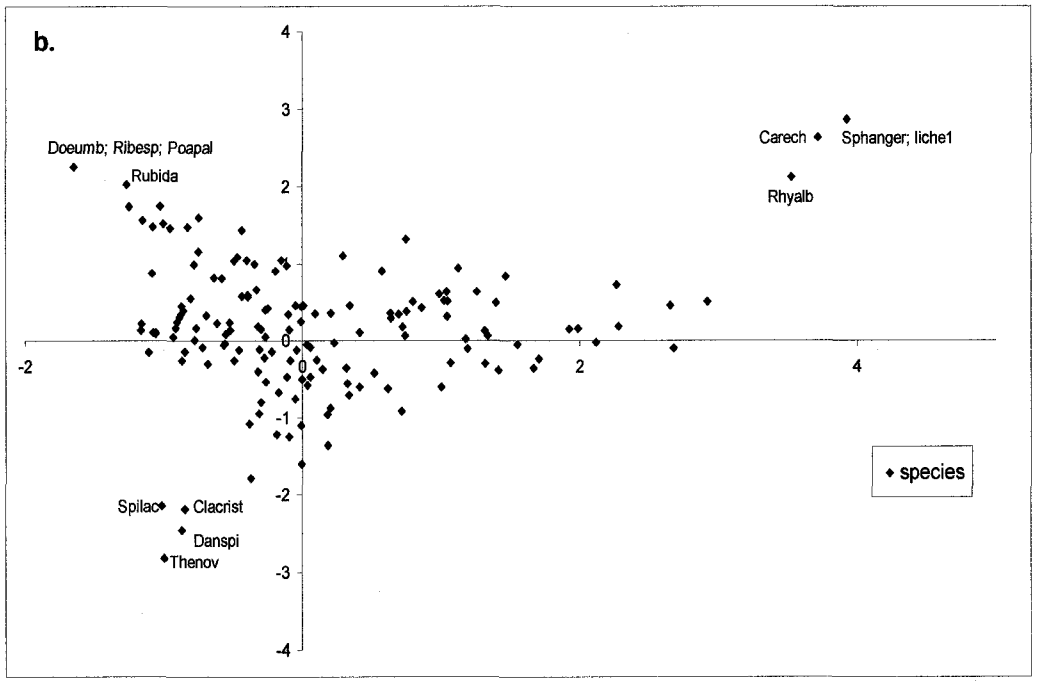




**Figure 2a**. Plot scores on 1st and 2nd axes of the CA ordination using all species data. Ten outlier plots were removed in this analysis, and species unique to these outlier plots were removed. Plots are colour coded according to site. Ellipses are drawn around the majority of plots belonging to individual sites. BA=Baleine; CA=Canso; CH=Chebucto Head; LI=Little Anse; PE=Peggy's Cove; TA=Taylor Head. **b.** Species scores on 1st and 2nd axes of the same ordination shown in Figure 2a. Sphanger=*S. angermanicum*; liche1=lichen 1; Carech=*C. echinata*; Rhyalb=*R. alba*; Spilac=*S. lacera*; Clacrist=*C. cristatella*; Danspi=*D. spicata*; Thenov=*T. noveboracensis*; Doeumb=*D. umbellata*; Ribesp=*Ribes* species; Poapal=*P. palustris*; Rubida=*R. idaea*. For eigenvalues and total inertia, see Table 4.

Table 4. Eigenvalues for the correspondence analysis using all species data, with 10 outlier plots removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.488 | 0.471 | 0.437 | 0.390 | 8.275 |
| Cumulative % variance | 5.9 | 11.6 | 16.9 | 21.6 | |

With 10 outlier plots removed, only one plot appears clearly separate from the main cluster at the extreme top right of the graph. This plot, PE-17, is a bog plot, differing from other nearby bog plots in its Cyperaceae, lichen and moss communities. Specifically, PE-17 has unique and large populations of *Carex echinata* and *Rhynchospora alba*, a unique lichen species (not identified), and the only population of *Sphagnum angustifolium* found at any of the sites.

The positive end of axis 1 is occupied by a mix of plots from three different sites. These plots all contain typical bog vegetation such as *D. rotundifolia, Kalmia polifolia, Myrica gale, S. purpurea, V. oxycoccus, T. caespitosum,* and *S. rubellum* or *S. fuscum.*

At the negative end of axis 1, there is a high degree of overlap between plots of Canso and Chebucto Head. Plots at the extreme end of this axis are dominated by tall shrub communities composed of *A. viridis* and *P. melanocarpa.* In general, they are moderately rich in vascular plants but have impoverished lichen and moss communities. The main cluster of plots from Canso and Chebucto Head is stretched along the positive side of axis 2. Although CAs do not use environmental data to separate plots, one can make inferences about possible underlying environmental conditions by examining the species present in each plot, and how plots relate to their neighbours in terms of the species composition and the general habitat requirements of those species. Therefore, plots appear to be separating along axis 2 according to a height gradient (or substrate

fertility factor), with tall shrubby plots at the upper end of axis 2, and shorter plant communities, found predominantly at Little Anse, at the negative end of axis 2. It appears that Canso and Chebucto Head share similar species composition and that plots from these two sites are partly distinguished by average vegetation height. Plots from Chebucto Head seem to be shorter, on average.

At the same end of axis 1, a number of plots from Peggy's Cove overlap the bottom half of this Canso-Chebucto Head cluster. These plots are heavily dominated by *C. conradii,* and also include low-lying ericaceous shrubs such as *G. baccata* and *K. angustifolia,* as well as *J. communis. C. terrae-novae* is the dominant lichen species in these plots. Several Taylor Head plots also exhibit this same assemblage of species.

The plots from Taylor Head are tightly clustered, with a small number of plots pulled further towards the bog and tree communities of the positive end of axis 1. In contrast to the forest plots from Canso, TA-17, also a forest plot (not shown), does not appear as an extreme outlier. Although the average vegetation height is greater than other coastal barrens plots, the dominant species in TA-17 is *Picea rubens* rather than *A. balsamea. P. rubens* is found in other plots, both at Taylor Head and Peggy's Cove. The forest community in TA-17 also appears younger than that in the Canso plots, judging by DBH of the trees. Other species in TA-17, such as *K. angustifolia, R. groenlandicum, C. trisperma, Sphagnum magellanicum,* and *P. schreberi,* are found elsewhere at Taylor Head and at other sites. TA-17 does differ from the rest of Taylor Head in its lichen communities, having no *C. terrae-novae,* but being home to *C. maxima* and *C. squamosa.*

Outside of the forest plot, the plant communities at Taylor Head are dominated by *E. nigrum, G. baccata, G. dumosa, J. communis, K. angustifolia, R. groenlandicum,* and *M. pensylvanica.* These plots are also extensively covered by *C. terrae-novae.*

In contrast, the plots from Baleine do not cluster, but rather are stretched out along the positive length of axis 1. The dominant species in the Baleine plots is *E. nigrum.* Other common species include *J. communis, K. angustifolia, R. chamaemorus, Carex nigra, Cladonia rangiferina,* and *C. terrae-novae.*

The negative end of axis 2 is occupied by a tightly grouped cluster of plots from Little Anse, representing the majority of plots from that site. These plots are almost completely covered by *E. nigrum*, with abundant *V. angustifolium, V. vitis-idaea, J. communis, M. canadense,* and *S. tridentata.* Dominant lichens and bryophytes include *C. rangiferina, P. schreberi*, and a liverwort (*Ptilidium pulcherrimum*). Three plots from Little Anse are far removed from this tight cluster. Two of these plots are taller shrubby plots dominated by *M. pensylvanica, C. nigra* and *O. cinnamomea*, and are located close to the tall shrubby plots from Canso, Chebucto Head and Peggy's Cove. The remaining plot is distinctive in having *E. nigrum* as the dominant species, and in having abundant *Gaultheria hispidula*, a higher number of *Sphagnum* species, and less representation of *O. cinnamomea.*

**All species**

Species loadings on the extreme positive end of axis 1 constitute a forest community of vascular plants, lichens and mosses that are representative of tree copses on the coastal barrens (Figure 2b). They were encountered at Canso, and, to a lesser extent, at Taylor Head. These copses constitute less than 10% of the total area of the coastal barrens, but those at Canso contain a distinctly different plant community from the dominant ericaceous shrub communities of the open barrens. The dominant vascular plant in this Canso forest community is *A. balsamea*, and its associated epiphytic lichens

are *U. filipendula*, *U. subfloridana* and *Bryoria trichodes*. *Parmelia squarrosa* was also highly represented at the Canso forest plots. With respect to mosses, *Herzogiella turfacea* was found in one of the Canso forest plots, the only time it was recorded at any of the sites.

At the opposite end of axis 1, both *E. eamesii* and *J. horizontalis* are obvious outliers. Unlike the tall and inland *A. balsamea*, these species form low-lying carpets near the shoreline. These two species are locally codominant in the near-shore areas of certain barren complexes, although it is apparent from the correspondence analysis that neither is a common species relative to other coastal barren plant communities.

Once the plots containing these outlier species were removed, species were shown to be overlaid on plots in which they were most abundant. Hydrophilic species such as *C. echinata, R. alba* and *S. angermanicum* load on the positive end of axis 1 overtop of bog plots from all sites. *Thelypteris noveboracensis, Spiranthes lacera, Danthonia spicata*, and *Cladonia cristatella* all load at the negative end of axis 2 over the plots from Little Anse, in which they were most commonly found. Shrubby species such as *Rubus idaea* and *Ribes* sp., as well as the forb *Doellingeria umbellata* and the grass *P. palustris,* load over the plots from Canso at the positive end of axis 2 and towards the negative end of axis 1.

**Common species**

Using the correspondence analysis of all plot data minus 10 outlier plots, I graphically overlaid the 10 most common species of the coastal barrens (Figure 3a). Most of the common species load in the middle of all the plots, indicating that they are relatively common at all sites. Nonetheless, it is possible to see slight differences in the

species loadings based on their abundance and distribution at the six sites. For example, *E. nigrum,* the most common species on the coastal barrens, loads closest to the plots from Baleine, Taylor Head and Little Anse, which are the sites at which it was most abundant. In contrast, *E. nigrum* loads furthest from the Canso plots, where it was not recorded. *O. cinnamomea* loads closest to the Canso plots, and furthest from the plots from Baleine.

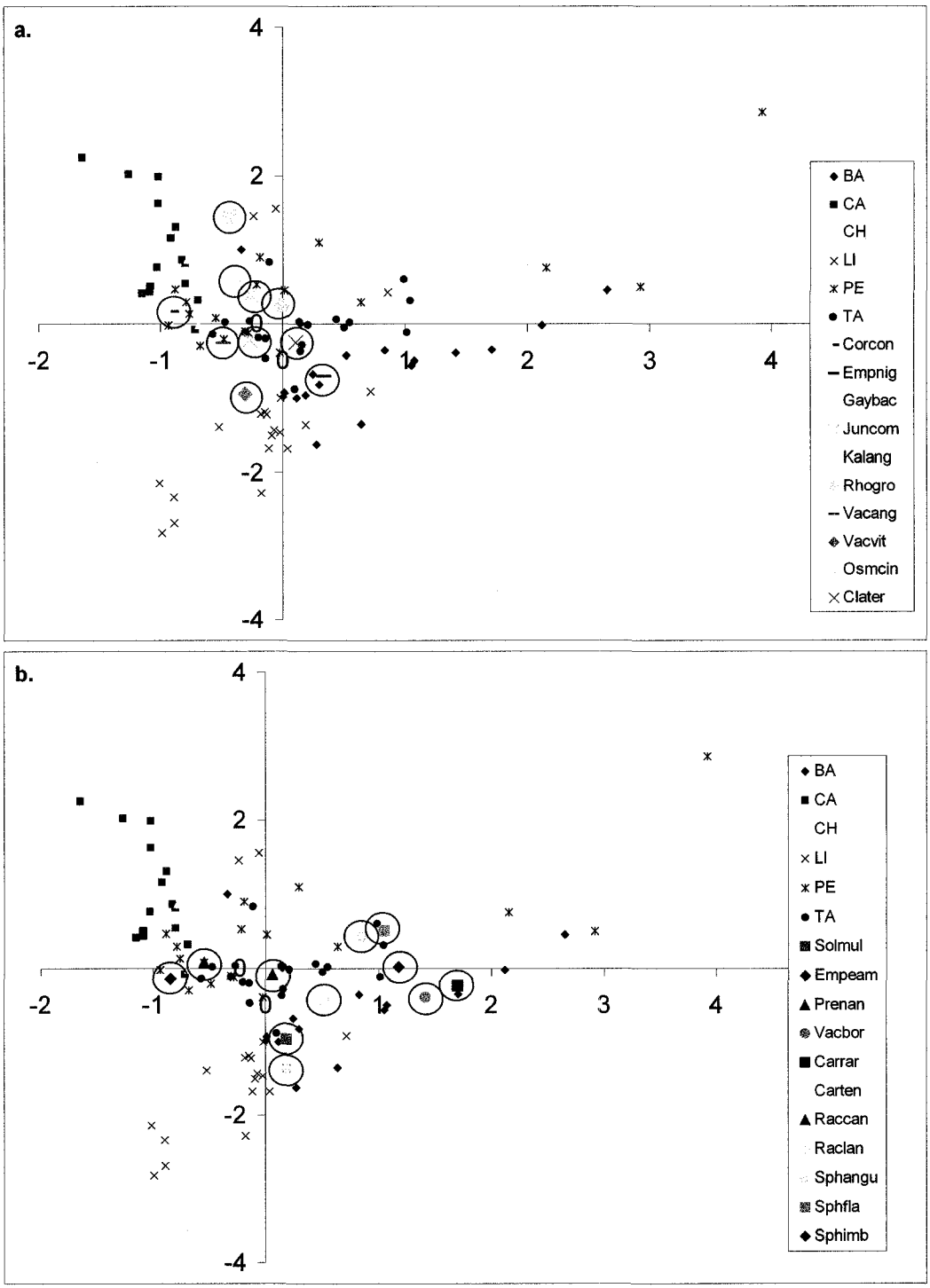



**Figure 3a.** The ten most common species by number of occurrences overlaid on the ordination shown in Figure 2a. Red circles highlight the common species. Corcon=*C. conradii*; Empnig=*E. nigrum*; Gaybac=*G. baccata*; Juncom=*J. communis*; Kalang=*K. angustifolium*; Rhogro=*R. groenlandicum*; Vacang=*V. angustifolium*; Vacvit=*V. vitis-idaea*; Osmcin=*O. cinnamomea*; Clater=*C. terrae-novae*.
**b.** Rare species overlaid on the ordination shown in Figure 2a. Red circles highlight the rare species. Solmul=*Solidago multiradiata*; Empeam=*E. eamesii*; Prenan=*Prenanthes nana*; Vacbor= *Vaccinium boreale*; Carrar=*C. rariflora*; Carten=*Carex tenera*; Raccan=*Racomitrium canescens*; Raclan=*R. lanuginosum*; Sphangu=*Sphagnum angustifolium*; Sphfla=*S. flavicomans*; Sphimb=*S. imbricatum*

**Rare species**

An overlay of rare species on the same analysis showed that most rare species load at different intervals along axis 1, and that the variation on axis 2 is quite small compared to the more dispersed loading of common species (Figure 3a). It appears that most of the rare species respond more to a water gradient (axis 1) than to a vegetation height gradient (axis 2). The highest score on positive axis 1 is *Carex rariflora*, which was found at Baleine in plots with other hydrophilic species such as *V. oxycoccus, T. caespitosum* and *M. gale. E. eamesii* was found at the opposite end of these species loadings, adjacent to plots from Canso, Chebucto Head and Peggy's Cove. It is also apparent that more species loadings are found among the plots from Baleine than near any other site. This result graphically confirms the disproportionate number of rare species that occur at Baleine.

**Correspondence analysis with equal weighting of species**

A correspondence analysis was performed using only presence-absence data (1s and 0s), rather than abundance data (frequency of occurrence), for all the plots at the six sites. This analysis therefore eliminated the effect of species' relative abundances in separating out the plots.

The analysis with presence-absence data from all species and all plots produced a graph with four extreme outliers: plots BA-01, BA-02, PE-07, and TA-01. These plots also appeared as outliers in the correspondence analysis using abundance data.

Once these four outliers are removed from the analysis, the graph shows increased overlap between plots of different sites (Figure 4). In the abundance-based correspondence analysis, PE-17 (a bog plot) is isolated at the extreme northwest of the

ordination. In the presence-absence correspondence analysis, PE-17 is grouped with other bog plots. As noted, there are fewer outlier plots produced with the presence-absence correspondence analysis (4 total) than with the abundance-based correspondence analysis (10 total).

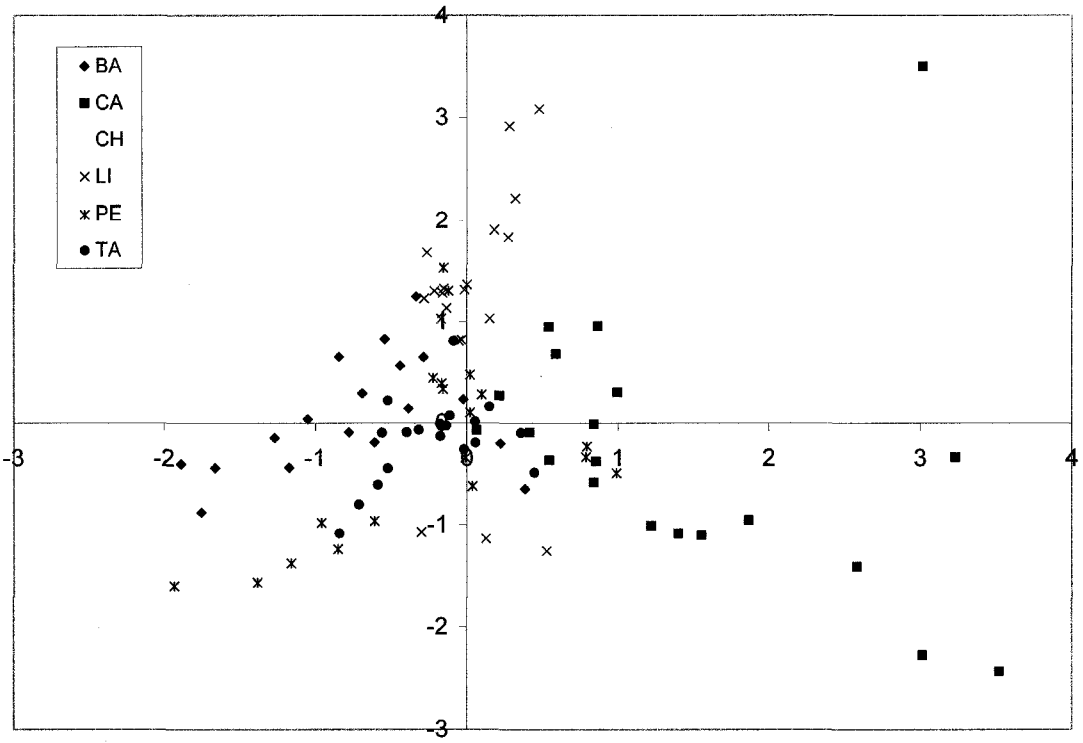



**Figure 4.** Plot scores on the 1st and 2nd axes of the CA ordination using all species data, with data in presence-absence format. All species are coded either 1 or 0 in the analysis to remove the effects of abundance data. Sites are identified by colour. Four outlier plots have been removed.

Table 5. Eigenvalues for the correspondence analysis using presence-absence data, with four outlier plots removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.416 | 0.362 | 0.326 | 0.310 | 9.051 |
| Cumulative % variance | 4.6 | 8.6 | 12.2 | 15.6 | |

A detrended correspondence analysis (DCA) was also performed with all plot data. The analysis produced four outliers: CA-10, CA-11, CH-01, and PE-07. These plots were also outliers in the correspondence analysis with all species. Once these

outliers were removed, the analysis produced a graph with a pattern of site separation similar to the correspondence analysis.

**Correspondence analysis – vascular plants**

A correspondence analysis was run using only vascular plant data from the plots to determine if vascular plants would have influence in separating out plots without the influence of lichen and moss species. The ordination produced four large outliers: BA-01, CH-01, CA-10, and CA-11. BA-01 had a single record for *I. setosa,* an unusually large population of *F. rubra,* and low species richness in general. CH-01 also had low species richness and was dominated by two uncommon species: *E. eamesii* and *J. horizontalis.* The plots from Canso contained unusual forest assemblages and were dominated by *A. balsamea.*

When the analysis was rerun without these four plots, there did not appear to be a large difference between the ordination using all species data and that using only vascular species data (Figure 5). The separation of sites is still preserved, although the high degree of overlap in some areas remains. This result indicates that plots are dominated by the influence of vascular plants in terms of the number and abundance of species. Accordingly, vascular plants have more weight in separating out plots as compared to lichens or mosses. This result is unsurprising given that vascular plant species dominate the species scores by virtue of their number and abundances.

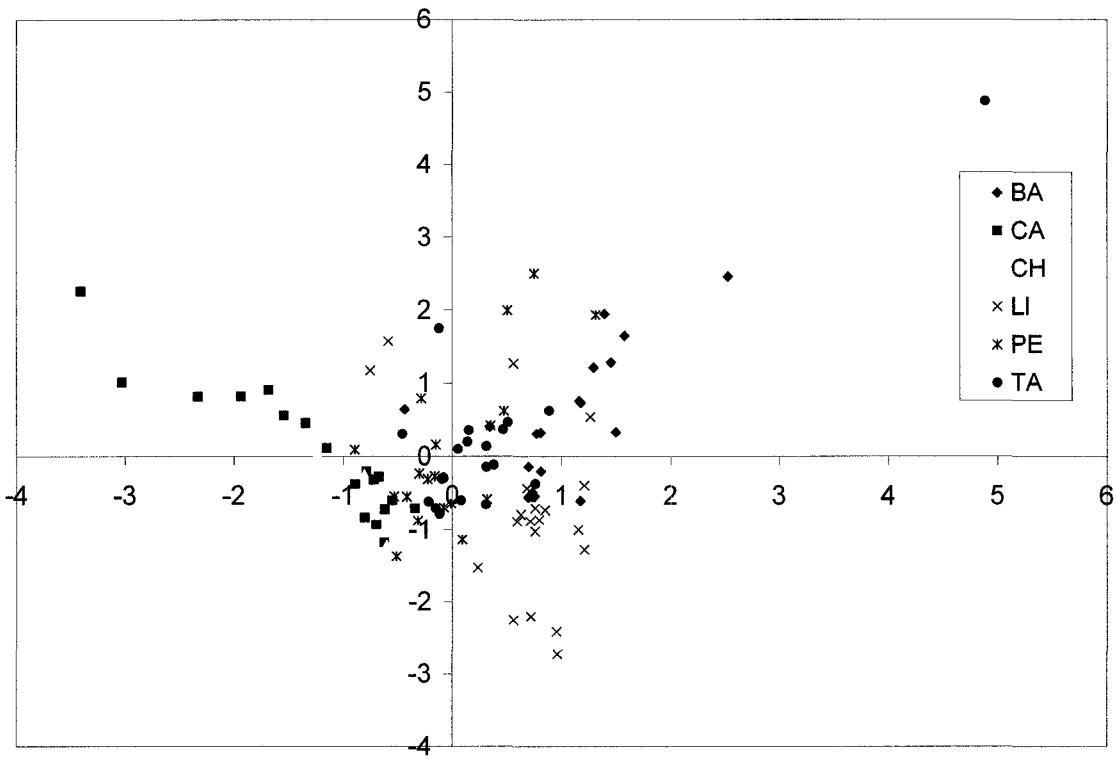



**Figure 5.** Plot scores on the 1st and 2nd axes of the CA ordination using only vascular species data. Four outlier plots have been removed. Plots are colour-coded according to site.

Table 6. Eigenvalues for the CA using only vascular plant data. Four outlier plots have been removed

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.530 | 0.452 | 0.450 | 0.387 | 7.560 |
| Cumulative % variance | 7.0 | 13.0 | 18.9 | 24.1 | |

**Common and rare species**

Overlaying the ten most common vascular species on the vascular plant CA produced results similar to the same analysis with all species data. Overlaying rare vascular species on the vascular plant CA also produced results previously seen in the all species CA.

**Correspondence analysis - lichens**

A correspondence analysis with all 43 lichen species produced a graph with 9 outliers. Once these outliers were removed, the cumulative variance explained (Table 7) was found to be higher than that of the ordination using all species data.

Table 7. Eigenvalues for the CA using only lichen plot data. Nine outlier plots have been removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.589 | 0.556 | 0.501 | 0.490 | 5.680 |
| Cumulative % variance | 10.4 | 20.1 | 29.0 | 37.6 | |

A graph of this ordination shows a tight cluster of plots from Baleine, Little Anse and Taylor Head (Figure 6). Only one plot from each of these sites occurs outside this main cluster. Almost 50% of the plots from Peggy's Cove also fall within this same cluster. The majority of the plots from Chebucto Head occur separately from this cluster and are also separate from each other. The plots from Canso load strongly on positive axis 1 and 2 and do not overlap with those from Chebucto Head or the main cluster, with the exception of one plot (CA-08).

When lichen species data are overlaid on this graph, certain types of species associate very strongly with the different substrate types. Epiphytic lichens that are found on trees and shrubs, such as *Ramalina* species, *Usnea* species and *Hypogymnia* species, overlay closely with the plots from Canso. Other disturbance-tolerant lichens, such as *Cladonia crispata,* also overlay closely with the plots from Canso. Lichens that load close to the plots from Peggy's Cove are all rock lichens, such as *Arctoparmelia centrifuga, Umbilicaria muehlenbergii,* and *Stereocaulon saxatile.* All of the caribou

lichens from the former *Cladina* load on the large cluster of plots from all sites, most of which are bog plots.

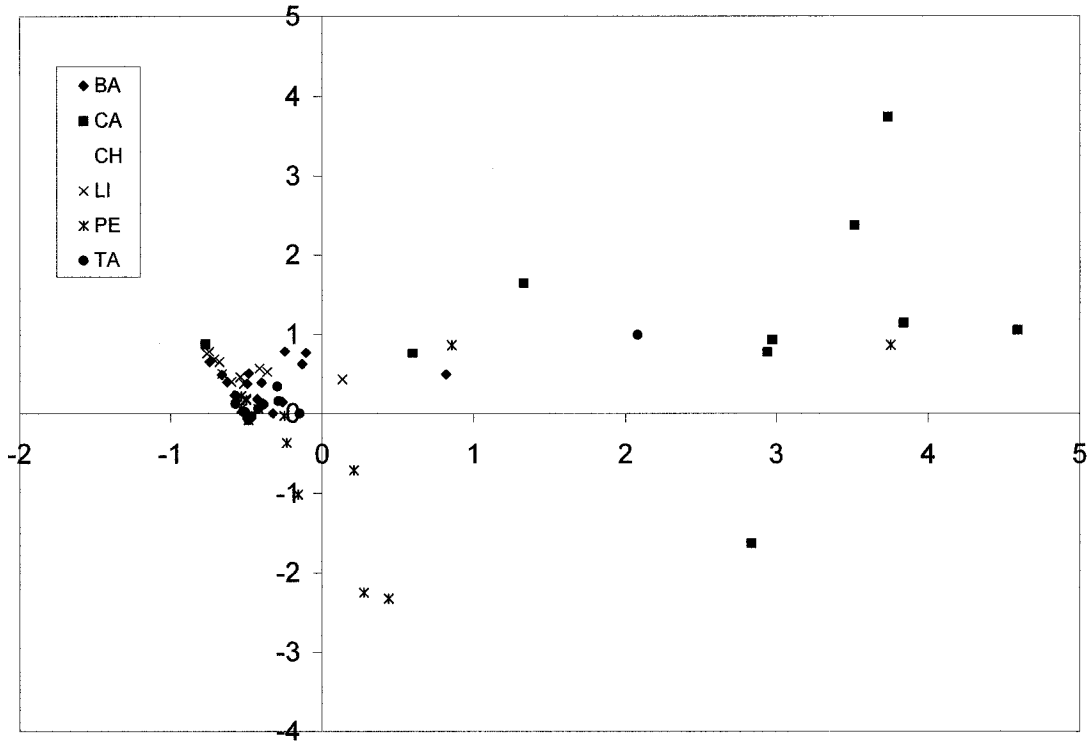



**Figure 6.** Plot scores on the 1st and 2nd axes of the CA ordination using only lichen plot data. Nine outlier plots have been removed. Plots are colour-coded according to site.

## Common species

When common species having greater than 50 total occurrences over all sites are overlaid on the lichen ordination, only two of these six species, *Hypogymnia physodes* and *Cladonia boryii,* load strongly on the first two axes (Figure 7). The other common lichens, consisting of *C. rangiferina, C. stygia, C. terrae-novae,* and *Cladonia uncialis* are clustered in a group near the majority of plots from Taylor Head, Little Anse, and Baleine.

Most of the non-"*Cladina*" *Cladonia* species loadings are very close to axis 1 and seem unaffected by axis 2. Those species' loadings that are most affected by axis 2

include lichens that live on woody substrate, such as *Ramalina* and *Hypogymnia* species, and rock lichens, such as *U. muehlenbergii, S. saxatile* and *A. centrifuga.* Nearly all the *Cladina* species are clustered in a tight group with the majority of the plots. Only *Cladonia boryii* loads closest to the other rock lichens.

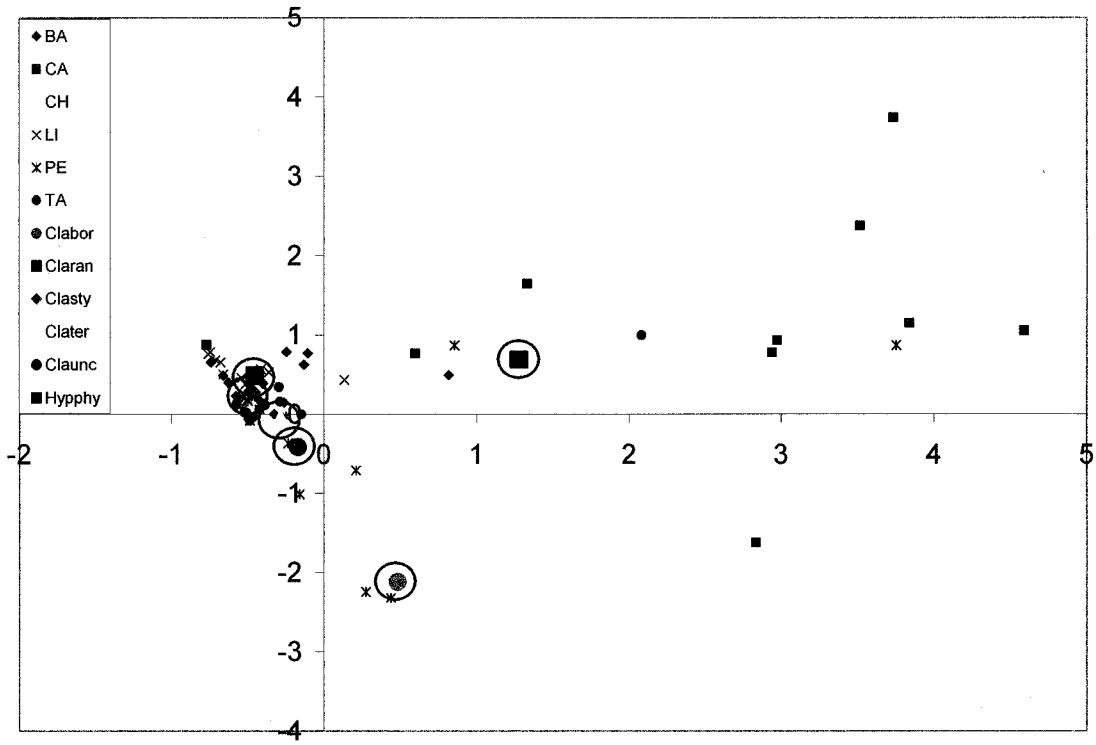



**Figure 7.** The 6 most common lichen species by number of occurrences overlaid on the ordination shown in Figure 6. Red circles highlight the common species. Clabor=*C. boryii*; Claran=*C. rangiferina*; Clasty=*C. stygia*; Clater=*C. terrae-novae*; Claunc=*C. uncialis*; Hypphy=*H. physodes*.

**Correspondence analysis - mosses**

A correspondence analysis with all 28 moss species produced outliers on both axes. The outlier plots were BA-15, CA-12, CA-16, CA-19, CH-05, PE-09, PE-13, and PE-14. BA-15 contained the only occurrence of the rare moss *Racomitrium lanuginosum.* CA-12 contained a comparatively large population of *Dicranum ontariense,* and CA-16, CA-19, CH-05, and PE-14 also had occurrences of this same uncommon forest species. PE-09 was also home to a large population of another wet forest moss: *Sphagnum fallax.*

Finally, PE-13 had the only occurrence of the other rare *Racomitrium* species: *R. canescens.*

When 8 outlying plots are removed, the graph of this analysis shows two distinct clusters on either side of axis 2 (Figure 8). On the positive end of axis 1, the cluster contains plots that on average have drier or rockier conditions and shallower substrate. On the negative end of axis 1, the cluster consists of plots from boggy areas. Both clusters contain plots from all sites. This pattern of intermixed plots from all sites was also seen in the correspondence analysis using all species data, where bog plots from all sites overlapped at the extreme positive end of axis 1 (Figure 2a).

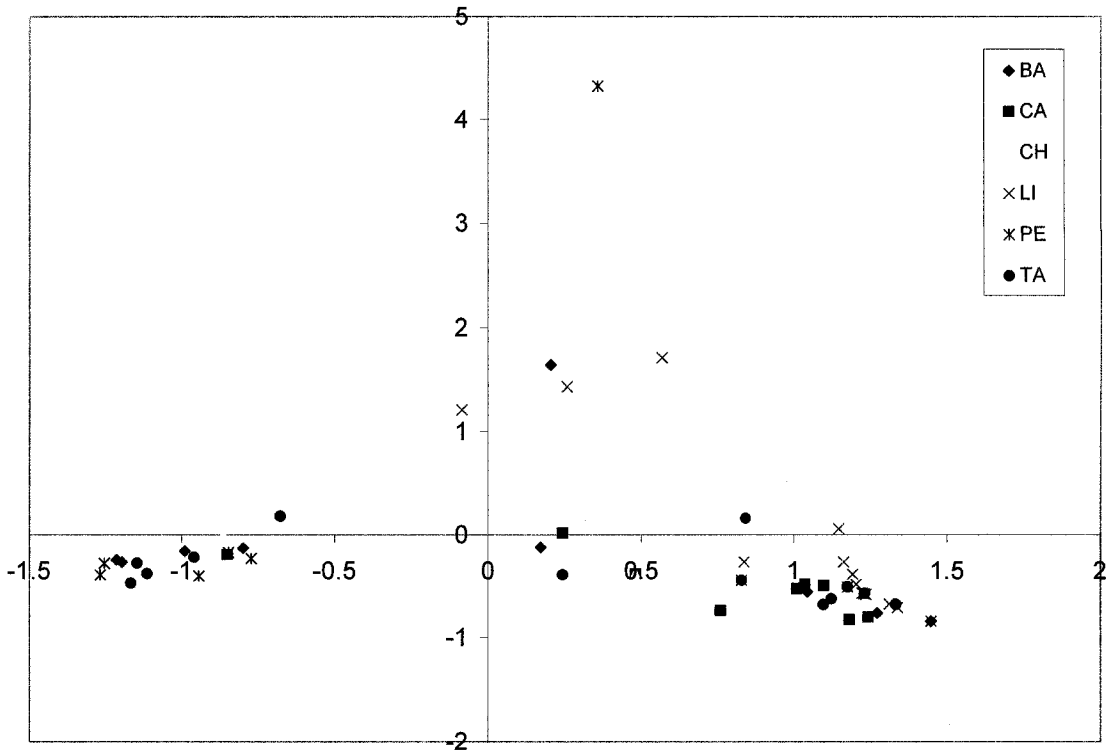



**Figure 8.** Plot scores on the 1st and 2nd axes of CA ordination using only moss data. Eight outlier plots have been removed. Plots are colour-coded according to site.

Table 8. Eigenvalues for the CA using only moss plot data. Eight outliers have been removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.894 | 0.801 | 0.680 | 0.598 | 8.420 |
| Cumulative % variance | 10.6 | 20.1 | 28.2 | 35.3 | |

**Common species**

When common moss species are overlaid on the graph, we see a gradient of species sorting out according to moisture conditions, as evidenced by the loading pattern of hydrophilic species (Figure 9a). On the positive end of axis 1 are drier-substrate forest species, such as *P. schreberi* and *Ptilidium pulcherrimum* (liverwort). On the negative end of axis 1, the hydrophilic *Sphagnum* species are ordered according to moisture gradient, with two classic bog hummock species, *S. rubellum* and *S. fuscum*, at the extreme end of the gradient. *S. magellanicum,* a cosmopolitan species with slightly drier habitat requirements, is located between forest species and the other *Sphagnum* species, as is *Sphagnum compactum.*

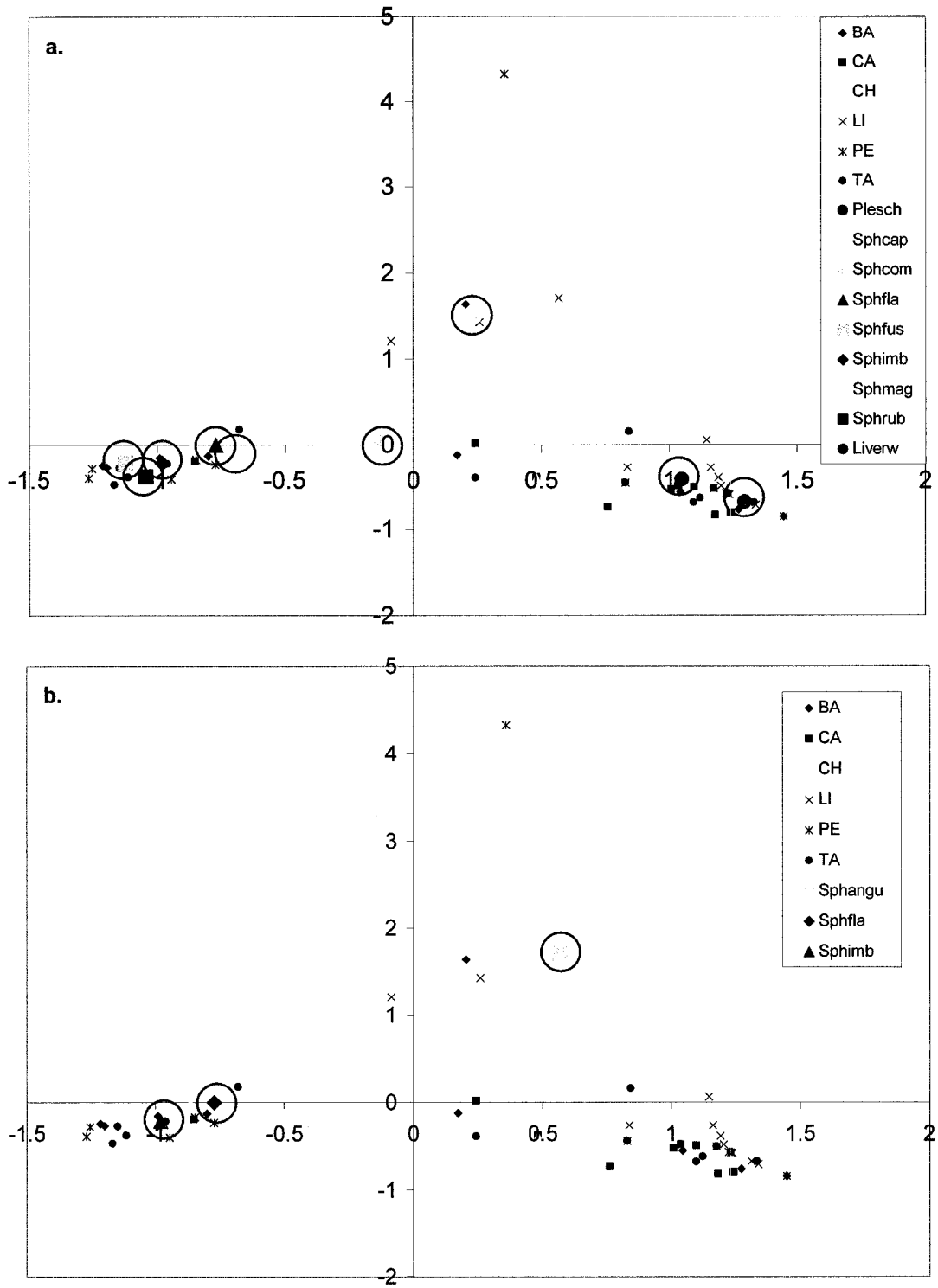



**Figure 9a**. The 9 most common moss species (including 1 liverwort) by number of occurrences overlaid on the ordination shown in Figure 8. Red circles highlight the common species. Plesch=*P. schreberi*; Sphcap=*S. capillifolium*; Sphcom=*S. compactum*; Sphfla=S. *flavicomans*; Sphfus=*S. fuscum*; Sphimb=*S. imbricatum*; Sphmag=*S. magellanicum*; Sphrub=*S. rubellum*; Liverw=liverwort (*P. pulcherrimum*).
**b.** Rare moss species overlaid on the ordination shown in Figure 8. Red circles highlight the rare species Sphangu=*S. angustifolium*; Sphfla=*S. flavicomans*; Sphimb=*S. imbricatum*.

**Rare species**

Two of the rare moss species, *Racomitrium canescens* and *R. lanuginosum*, were large outliers and removed from the CA of all moss data. *R. canescens* loaded strongly on the negative end of axis 1, and *R. lanuginosum* loaded strongly on the positive end of axis 1.

The three remaining rare mosses load along the main moisture gradient of axis 1 (Figure 9b). Both *S. flavicomans* and *S. imbricatum* load in the main *Sphagnum* cluster on the negative end of axis 1. *S. angustifolium* loads strongly on axis 2, one of the only moss species to do so. It was found in a single plot at Little Anse and at no other sites.

**Multi-dimensional scaling (MDS)**

The MDS tests confirmed the same site-level vegetation patterns that were obtained with the CAs; namely, that vegetation community composition differed among sites. Therefore, only the CA results are reported.

**Analysis of similarities (ANOSIM)**

For an analysis using all species data, an ANOSIM revealed a global separation of moderate effect size (R= 0.4; $P$ =0.001) in plant communities between sites (Table 9). Furthermore, it detected similar plant and lichen communities among the three southern sites (TA, CH, PE), and revealed that moss communities differed more among the three southern sites as compared to vascular plants and lichens. Different plant communities were found to occur among the three northern sites (BA, LI, CA). Post-hoc unplanned pairwise comparisons showed that the three southern sites showed statistically significant, albeit very small, separations. The southern sites were also significantly separated from

the three northern sites. These three northern sites were in turn also separated from one another.

In general, the three southern sites shared a dominant plant community consisting of *J. communis, E. nigrum, K. angustifolia, V. angustifolium,* and *C. terrae-novae.* The three northern sites contained different species and abundances than the aforementioned communities, and each site had a unique plant community of its own. Baleine was dominated by *E. nigrum, J. communis, V. angustifolium, C. terrae-novae,* and *T. caespitosum.* Little Anse was dominated by *E. nigrum, V. vitis-idaea, V. angustifolium, C. rangiferina,* and *S. tridentata.* Canso was dominated by *K. angustifolia, O. cinnamomea, G. baccata, V. angustifolium,* and *C. conradii.*

Further analysis showed that vascular plants alone have nearly identical separation patterns between sites as compared to the analysis using all species data (Table 9). Lichens showed differences between two southern sites, Taylor Head and Chebucto Head, which were not seen in the analysis using all species data and vascular plants alone. Chebucto Head was more lichen-rich than Taylor Head in terms of number of species, and also contained several species of rock lichen that were not seen at Taylor Head, such as *A. centrifuga, L. papulosa, S. saxatile,* and *U. muehlenbergii.* Taylor Head was overwhelmingly dominated by *C. terrae-novae* and tended to have more wet-tolerant species, such as *C. stygia.*

Mosses showed no separation among sites for some north-south comparisons, such as Canso and Chebucto Head (Table 9). In general, mosses showed fewer dissimilarities among sites than lichens. Both lichens and mosses tended to show lower global and pairwise separation between sites than vascular plants.

Species abundance scores were transformed to presence/absence scores in order to assess the contribution of species composition (rather than species' relative abundances) to separation of sites. After this transformation, the ANOSIM test showed patterns similar to those derived from both composition and abundance data. Likewise, when only the twenty or ten most common species (Table 1) were used to differentiate plots, sites showed the same patterns of difference as the analyses with all species considered together. Results of the CAs, the MDS and the ANOSIMs suggest sites differ both in species composition and abundance.

Table 9. ANOSIM - Pairwise site differences in species composition and abundance for six coastal barren sites in Nova Scotia.

| Site Pair[a] | Separation distance (R)[b] All Species[d] | *P*[c] | Separation distance (R) Vascular Plants[e] | *P* | Separation distance (R) Lichens[f] | *P* | Separation distance (R) Bryophytes[g] | *P* |
|---|---|---|---|---|---|---|---|---|
| BA vs. CA (NN) | 0.77 | 0.0001 | 0.77 | 0.0001 | 0.49 | 0.0001 | 0.25 | 0.0003 |
| BA vs. LI (NN) | 0.28 | 0.0001 | 0.28 | 0.0001 | 0.14 | 0.0020 | 0.28 | 0.0009 |
| CA vs. LI (NN) | 0.60 | 0.0001 | 0.60 | 0.0001 | 0.35 | 0.0070 | 0.22 | 0.0030 |
| BA vs. CH (NS) | 0.47 | 0.0001 | 0.48 | 0.0001 | 0.34 | 0.0001 | 0.19 | 0.0030 |
| BA vs. TA (NS) | 0.34 | 0.0001 | 0.32 | 0.0001 | 0.27 | 0.0002 | 0.33 | 0.0003 |
| BA vs. PE (NS) | 0.55 | 0.0001 | 0.60 | 0.0001 | 0.14 | 0.0030 | 0.12 | 0.0290 |
| CA vs. PE (NS) | 0.47 | 0.0001 | 0.48 | 0.0001 | 0.18 | 0.0130 | 0.18 | 0.0060 |
| CA vs. CH (NS) | 0.26 | 0.0001 | 0.26 | 0.0001 | 0.35 | 0.0002 | 0.06 | 0.1100 |
| CA vs. TA (NS) | 0.43 | 0.0001 | 0.40 | 0.0001 | 0.55 | 0.0001 | 0.13 | 0.0190 |
| LI vs. CH (NS) | 0.47 | 0.0001 | 0.47 | 0.0001 | 0.33 | 0.0001 | 0.38 | 0.0001 |
| LI vs. TH (NS) | 0.46 | 0.0001 | 0.47 | 0.0001 | 0.40 | 0.0001 | 0.08 | 0.0300 |
| LI vs. PE (NS) | 0.57 | 0.0001 | 0.62 | 0.0001 | 0.17 | 0.0005 | 0.44 | 0.0002 |
| CH vs. PE (SS) | 0.04 | 0.1000 | 0.04 | 0.1000 | 0 | 0.4400 | 0.13 | 0.0250 |
| CH vs. TA (SS) | 0.17 | 0.0001 | 0.13 | 0.0010 | 0.32 | 0.0001 | 0.23 | 0.0020 |
| PE vs. TA (SS) | 0.14 | 0.0006 | 0.15 | 0.0004 | 0.06 | 0.0390 | 0.30 | 0.0008 |

[a] Sites are: BA (Baleine), LI (Little Anse), CA (Canso), TA (Taylor Head), CH (Chebucto Head), PE (Peggy's Cove); The geographic comparison (N = North vs. S = South) is given in brackets after the site acronyms.
[b] R ranges from 0 to 1.0 with 1.0 representing maximum and 0, minimum separation among groups.
[c] *P* values deemed statistically significant using Bonferroni rejection criterion at $\alpha = 0.05$ adjusted for *k* multiple tests ($P_{rejection} = \alpha/k = 0.003$)
[d] Global R = 0.40; *P* = 0.0001 [e] Global R = 0.41; *P* = 0.0001 [f] Global R = 0.24; *P* = 0.0001 [g] Global R = 0.22; *P* = 0.0001

**Question 2 - Which environmental factors are correlated with plant community structure?**

**Canonical correspondence analyses with all species**

In the canonical correspondence analysis with all species data, two large outliers caused the majority of species' loadings to be weak on the first two axes. Once these two outlier forest species (*A. balsamea* and *U. filipendula*) were removed, the ordination was more successful in distinguishing relationships between environmental variables and individual species (Table 10)

Table 10. Eigenvalues for the CCA ordination using all species and thirty environmental variables. Two outlier species were removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.490 | 0.413 | 0.380 | 0.336 | 10.943 |
| Species-environment correlations | 0.942 | 0.925 | 0.893 | 0.871 | |
| Cumulative percentage variance | | | | | |
| of species data | 4.5 | 8.3 | 11.7 | 14.8 | |
| of species-environment relation | 11.1 | 20.5 | 29.1 | 36.7 | |
| Sum of all canonical eigenvalues | | | | 4.412 | |

*Monte Carlo tests
Significance of the first canonical axis: F-ratio 4.175; P-value 0.0860
Significance of all canonical axes: F-ratio 2.004; P-value 0.0020

**Environmental variables**

Judging by the arrow lengths of some of the thirty measured environmental variables, several environmental variables were not important in accounting for species composition and abundance. For example, elevation, substrate Cu, rock exposure, temporal substrate moisture range, and substrate depth range all have very short arrows, indicating that these variables are not strongly associated with any particular species or

sites. These variables are not shown in Figure 10 in order to better display the important variables.

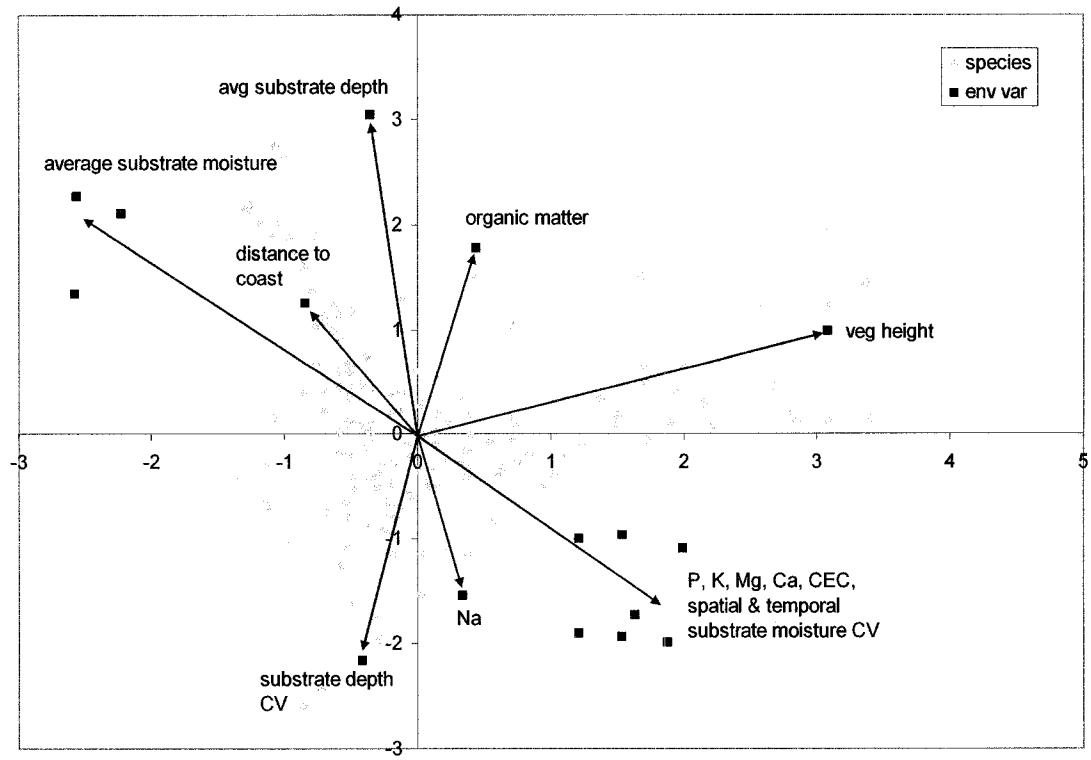



**Figure 10.** Species scores on the 1st and 2nd axes of the CCA ordination using all species data and 30 environmental variables. Environmental variables are indicated by the red arrows and pink squares. Species are represented by the grey diamonds. Two outlier species were removed.

On a graph of axes 1 and 2, there are several groups of strongly loading environmental variables. One of these groups consists of average temporal substrate moisture content, minimum spatial substrate moisture content, maximum spatial substrate moisture content (all three variables are grouped as average substrate moisture), distance to coast, substrate depth average, and organic matter. Species associated with high values of this group of variables include many hydrophilic species, such as *Larix larcina, Carex exilis, Sphagnum papillosum,* and *R. alba.* Therefore, when average temporal and spatial moisture conditions, substrate depth, distance to coast, and organic matter values are high, these species are likely to occur.

A second group of environmental variables loads opposite to this first group (Figure 10). This second group includes the following environmental variables: temporal substrate moisture content CV, Mg, Ca, K, P, and CEC. Another environmental variable loading nearby this last group is Na. Species closely associated with this grouping of variables include *Rosa carolina, P. glauca, Rubus pubescens, Hypogymnia tubulosa,* and *Rosa nitida.* These species do not overlap as closely with the environmental variables as was seen in group 1.

These two sets of variables load in opposite directions and are therefore inversely related to one another. For example, when distance to coast is great, nutrient levels are low. Species loading opposite to an environmental variable are not commonly associated with that variable. For example, *P. glauca* loads opposite to distance to coast. Therefore, this species is not found as far inland as other species, which is consistent with what we know of this species' ecology and its role as the dominant tree species along the coast.

Another environmental variable of note is vegetation height (Figure 10). This variable loads orthogonally to the other two groups of variables and is therefore independent of them; that is to say, that vegetation height is independent of such variables as distance to coast or substrate depth average. Species found growing in areas of tall vegetation include *Dryopteris carthusiana, C. angustifolium, P. palustris, R. idaea,* and *Prunus pensylvanica.* A cluster of species loads in the same direction as the variable vegetation height, and all these species were found in forest island plots. *Bryoria trichodes, Usnea subfloridana, H. turfacea, Parmelia squarrosa, L. borealis, and Brachythecium velutinum* were all found co-occurring in the forest plots at Canso.

**Common species**

When the most common ten species of the coastal barrens (in terms of number of occurrences; 200+ occurrences over all sites) are highlighted on the ordination, they load in a cluster central to other species loadings (Figure 11a). This result indicates that these abundant species were frequently encountered at all sites and plots, and thus contribute little power towards resolving plant community differences between plots. The only species that pulled strongly towards the positive end of axis 1 is *O. cinnamomea*, which appears to respond to the vegetation height gradient. The species loadings exhibit very little spread along axis 2, indicating that the species respond minimally to environmental gradients represented by this axis.

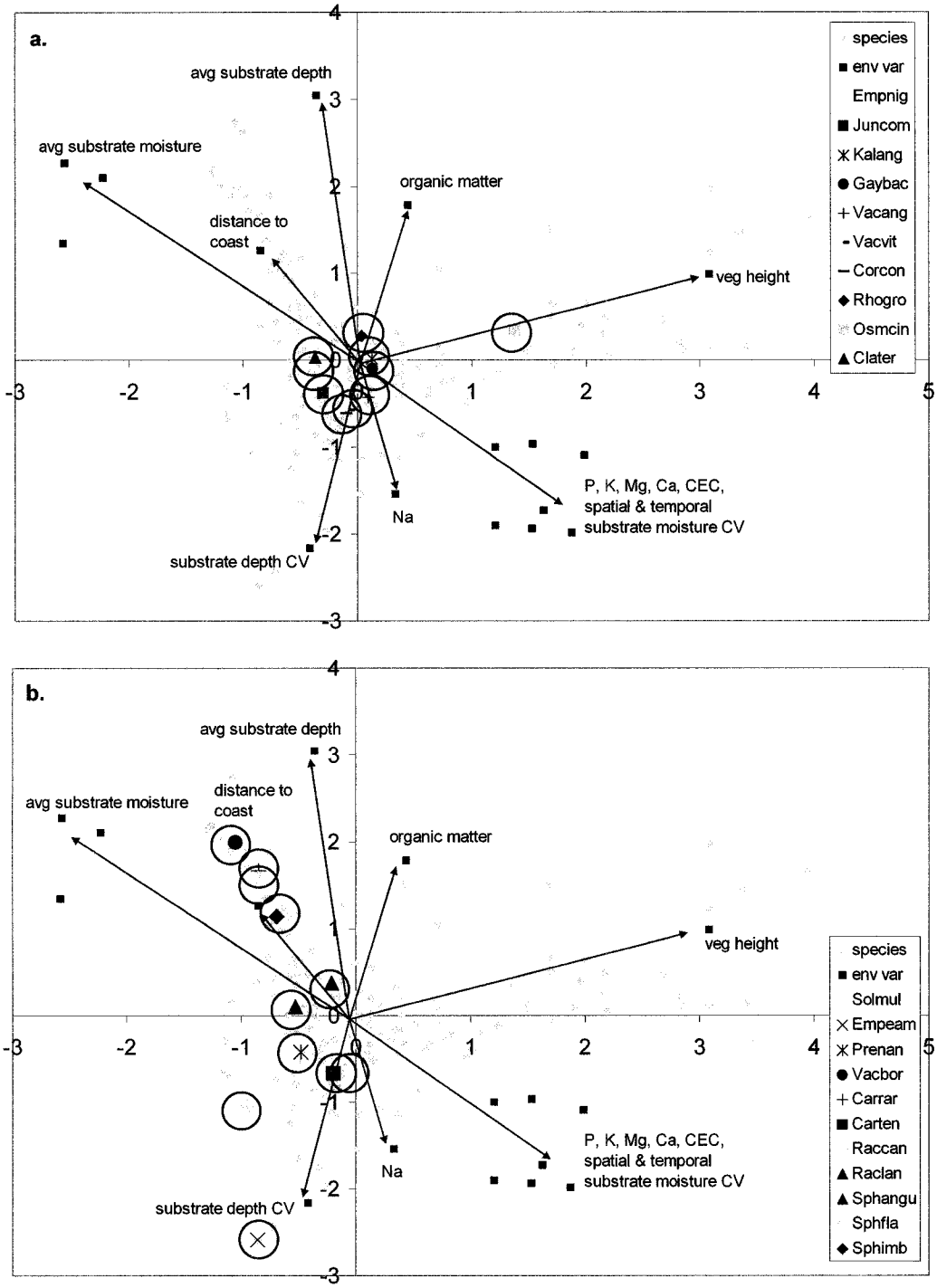



**Figure 11a.** The ten most common species by number of occurrence overlaid on the ordination shown in Figure 10. Red circles highlight the common species. Corcon=*C. conradii*; Empnig=*E. nigrum*; Gaybac=*G. baccata*; Juncom=*J. communis*; Kalang=*K. angustifolium*; Rhogro=*R. groenlandicum*; Vacang=*V. angustifolium*; Vacvit=*V. vitis-idaea*; Osmcin=*O. cinnamomea*; Clater=*C. terrae-novae*. **b.** Rare species overlaid on the ordination shown in Figure 10. Red circles highlight the rare species. Solmul=*Solidago multiradiata*; Empeam=*E. eamesii*; Prenan=*Prenanthes nana*; Vacbor= *Vaccinium boreale*; Carrar=*C. rariflora*; Carten=*Carex tenera*; Raccan=*Racomitrium canescens*; Raclan=*R. lanuginosum*; Sphangu=*Sphagnum angustifolium*; Sphfla=*S. flavicomans*; Sphimb=*S. imbricatum*

**Rare species**

In general, rare species loadings exhibit greater spread along axis 2 (Figure 11b), the exposure-moisture gradient, than common species. Rare species load on both sides of this axis. *Vaccinium boreale, C. rariflora, S. imbricatum, S. flavicomans, S. angustifolium,* and *R. lanuginosum* all occur on the positive side of axis 2, whereas *Prenanthes nana, Solidago multiradiata, Carex tenera, R. canescens,* and *E. eamesii* all occur on the negative side of axis 2.

Rare species appear to segregate out fairly evenly along a gradient of distance from coast/substrate moisture. Species loadings have very limited spread on axis 1, where vegetation height is the dominant environmental gradient. Most species load at the negative end of this axis, indicating that these rare species all occur in habitats characterised by low to intermediate vegetation height.

**Partial canonical correspondence analysis**

The results of this analysis indicate that the amount of variation present in the species data (total inertia) is 10.964. The additional variation explained by environmental variables is 3.785, and the amount of variation explained by the sites is 1.128.

**Canonical correspondence analysis - vascular plants**

A canonical correspondence analysis on plot data consisting of only vascular species identified two outlier species: *A. balsamea* and *L. borealis*. These two forest species were recoded in two forest plots at Canso. These species and the plots in which they are found are consistently identified as outliers in both the CAs and the CCAs, and they were also removed from this CCA.

Table 11. Eigenvalues for the CCA using only vascular plants and thirty environmental variables. Two outlier species were removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.465 | 0.392 | 0.368 | 0.326 | 8.261 |
| Species-environment correlations | 0.936 | 0.880 | 0.911 | 0.842 | |
| Cumulative percentage variance | | | | | |
| of species data | 5.6 | 10.4 | 14.8 | 18.8 | |
| of species-environment relation | 12.4 | 22.8 | 32.6 | 41.3 | |
| Sum of all canonical eigenvalues | | | | | 3.758 |

*Monte Carlo tests
Significance of the first canonical axis: F-ratio 5.245; P-value 0.0320
Significance of all canonical axes: F-ratio 2.448; P-value 0.0020

The graph of this analysis (Figure 12) shows species loading along similar gradients observed in the CCA with all plot data (Figure 10). Species loadings are again most strongly correlated with the distance to coast/substrate moisture gradient, and also by the vegetation height gradient along axis 1. The forest plots at Canso appear to be distinct from other plots in their community of vascular plants.

Common and rare species are also distributed similarly to the all species CCA (Figure 11a, b) and are associated with the same environmental gradients as noted in the all species CCA.

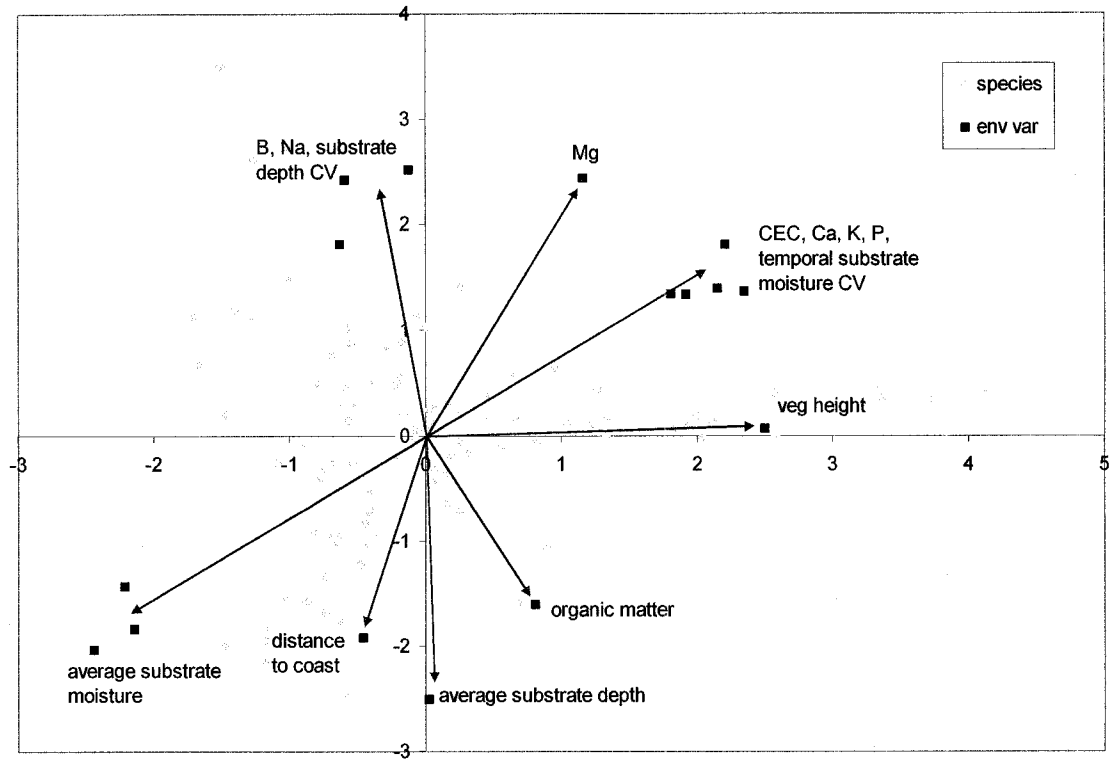



**Figure 12.** Species scores on the 1st and 2nd axes of the CCA ordination using only vascular plant data and 30 environmental variables. Environmental variables are indicated by the red arrows and pink squares. Species are represented by the grey diamonds. Two outlier species were removed.

## Canonical correspondence analysis - lichens

The CCA using only lichen data produced an initial graph with one large outlier, *Melanelia stygia.* This species was only found at one plot at Peggy's Cove and was not represented at any other sites. Once this outlier was removed, the first eigenvalue of the new analysis remained high, indicating that most of the variation in lichen species is explained by this first axis (Table 12).

Table 12. Eigenvalues for the CCA ordination using only lichen species and 30 environmental variables. One outlier species was removed.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.722 | 0.416 | 0.340 | 0.302 | 9.158 |
| Species-environment correlations | 0.969 | 0.876 | 0.884 | 0.793 | |
| Cumulative percentage variance | | | | | |
| of species data | 7.9 | 12.4 | 16.1 | 19.4 | |
| of species-environment relation | 20.7 | 32.6 | 42.3 | 51.0 | |
| Sum of all canonical eigenvalues | | | | | 3.493 |

*Monte Carlo tests
Significance of the first canonical axis: F-ratio 5.303; P-value 0.1100
Significance of all canonical axes: F-ratio 1.318; P-value 0.0560

At the positive end of axis 1, average vegetation height loads separately from all the other environmental variables (Figure 13). Directly opposite from it are measures of substrate moisture conditions, both temporal and spatial. The positive end of axis 2 is dominated by elevation, rock exposure and substrate depth CV, which load opposite to pH, B, N, substrate depth average, and organic matter.

Lichen species load most strongly on the first axis. Several lichens found in forest islands, such as *B. trichodes, U. subfloridana, U. filipendula,* and *P. squarrosa* load closest to the vegetation height variable. Less strongly correlated with the vegetation height variable are lichen species associated with shrub habitat, including *H. physodes, H. tubulosa, Ramalina roesleri* and *R. dilacerata.* These species appear to be correlated with increased substrate depth and pH, as they are also pulled to the negative side of axis 2. Lichens with rocky substrate requirements seem to load most strongly on positive axis 2 by such variables as elevation, substrate depth CV and rock exposure. These rock species include *C. strepsilis, S. saxatile, U. muehlenbergii,* and *L. papulosa.* The remaining common *Cladina* lichens form a tight cluster with little spread on any axis.

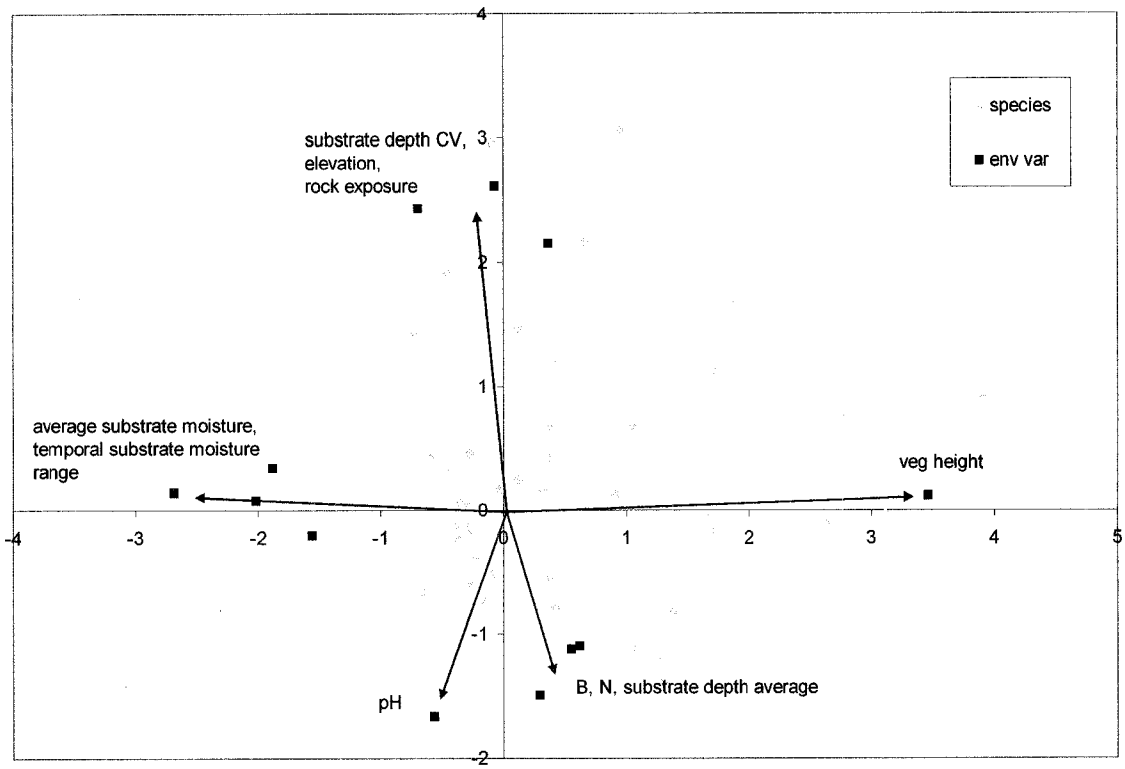



**Figure 13.** Species scores on the 1st and 2nd axes of the CCA ordination using only lichen species data and 30 environmental variables. Environmental variables are indicated by the red arrows and pink squares. Species are represented by the grey diamonds. One outlier species was removed.

## Common species

Most of the common lichen species found on the coastal barrens are from the *Cladina* clade. These species do not seem to be particularly affected by the measured environmental variables (Figure 14). One exception to this observation is *C. boryii,* which loads strongly on axis 2 near elevation, substrate depth CV and rock exposure. *Hypogymnia physodes,* a lichen found on bark and woody substrate, loads strongly on axis 1 towards vegetation height.

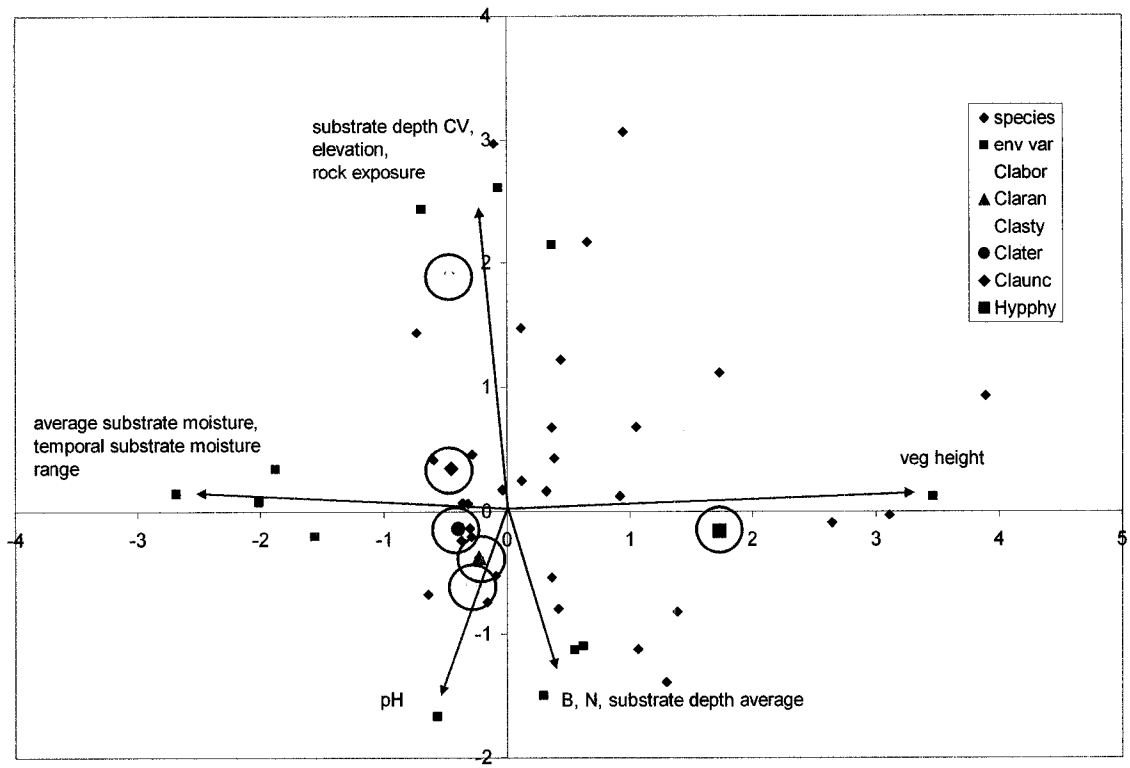



**Figure 14.** The 6 most common lichen species by number of occurrences overlaid on the CCA ordination shown in Figure 13. Red circles highlight the common species. Clabor=*C. boryii*; Claran=*C. rangiferina*; Clasty=*C. stygia*; Clater=*C. terrae-novae*; Claunc=*C. uncialis*; Hypphy=*H. physodes*

## Canonical correspondence analysis - mosses

A CCA using only moss species data yielded high eigenvalues on the first three axes, higher than the same analyses using only vascular plant data or only lichen data (Table 13).

Table 13. Eigenvalues for the CCA ordination using only moss species data and 30 environmental variables.

| | Axes | | | | Total inertia |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Eigenvalues | 0.790 | 0.601 | 0.525 | 0.459 | 12.065 |
| Species-environment correlations | 0.951 | 0.928 | 0.891 | 0.794 | |
| Cumulative percentage variance | | | | | |
| of species data | 6.6 | 11.5 | 15.9 | 19.7 | |
| of species-environment relation | 14.5 | 25.5 | 35.2 | 43.6 | |
| Sum of all canonical eigenvalues | | | | | 5.449 |

*Monte Carlo tests
Significance of the first canonical axis: F-ratio 3.575; P-value 0.3140
Significance of all canonical axes: F-ratio 1.449; P-value 0.0220

On the positive side of axis 1, the strongest loading variables are substrate nutrients, such as Ca, Mg, K, P, B, and CEC (Figure 15). Also loading on this side of axis 1 are measures of substrate moisture CV and substrate depth CV. Opposite these variables on the negative side of axis 1 are average substrate moisture conditions, average substrate depth, organic matter, and distance to coast. These two sets of variables are inversely related. Therefore, when distance to coast is high, substrate depth CV, substrate moisture CV and substrate nutrient levels are low. The variables Fe and pH load most strongly on the positive side of axis 2, and temporal range in substrate moisture conditions loads on the negative side of this axis. Unlike all the other CCAs, the CCA with moss species data does not show vegetation height as an important environmental variable.

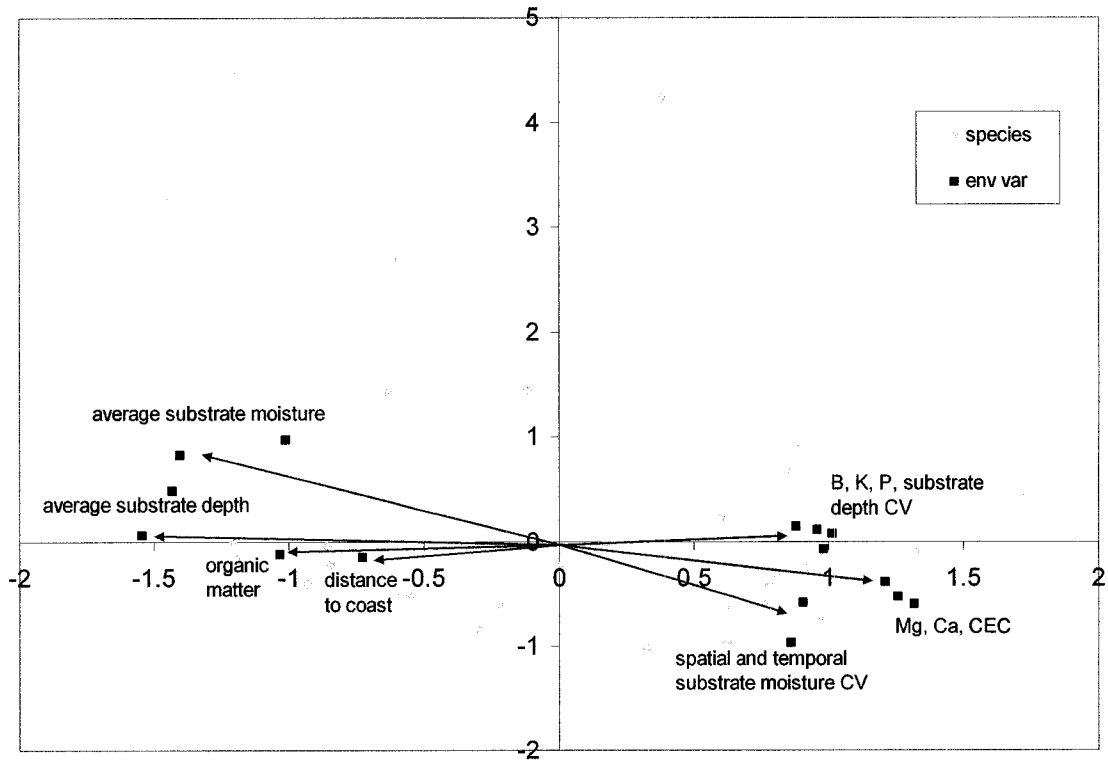



**Figure 15.** Species scores on the 1st and 2nd axes of the CCA ordination using only moss species data and 30 environmental variables. Environmental variables are indicated by the red arrows and pink squares. Species are represented by the grey diamonds.

In general, species loading on the positive side of axis 1 tend to be forest species, such as *D. ontariense, Hylocomium splendens, P. schreberi,* and the liverwort *P. pulcherrimum.* Also on the positive end of this axis is *R. canescens.* According to the CCA, these species are all associated with low substrate moisture, substrate depth variability and low levels of organic matter, but higher levels of substrate nutrients. They are also found closer to the coast. In contrast, species on the negative end of axis 1 are almost exclusively *Sphagnum* species, including *Sphagnum papillosum, S. fuscum, S. flavicomans, S. imbricatum,* and *S. rubellum.* These species are found in conditions of high substrate moisture content, high substrate depth, high organic matter content, far from the coast, and with low substrate nutrient levels. On this side of axis 2, the ecological niches of these *Sphagnum* species are preserved. For example, *S. fuscum*

typically grows on the side and bottom of bog hummocks, whereas *S. rubellum* grows on top of these hummocks in slightly drier habitat. On the CCA, we can see that *S. fuscum* loads closer to the high average moisture conditions than *S. rubellum. Sphagnum magellanicum,* a cosmopolitan species, is found most strongly associated with pH and Fe on axis 2. *S. angustifolium* also loads very strongly on this axis.

**Common species**

Common moss species (Figure 16a) do not load in as tight a cluster as common vascular or common lichen species (Figure 14). The species tolerant of the most intermediate conditions are *S. compactum* and *S. capillifolium.* Two forest species, *P. schreberi* and the liverwort *P. pulcherrimum,* occur at the positive end of axis 1 and are correlated with less variability in substrate moisture, less organic matter, higher substrate nutrient levels, and conditions closer to the coast. All the common *Sphagnum* species load opposite to these forest species in wetter and nutrient poor conditions. Only *S. magellanicum* loads strongly on axis 2.

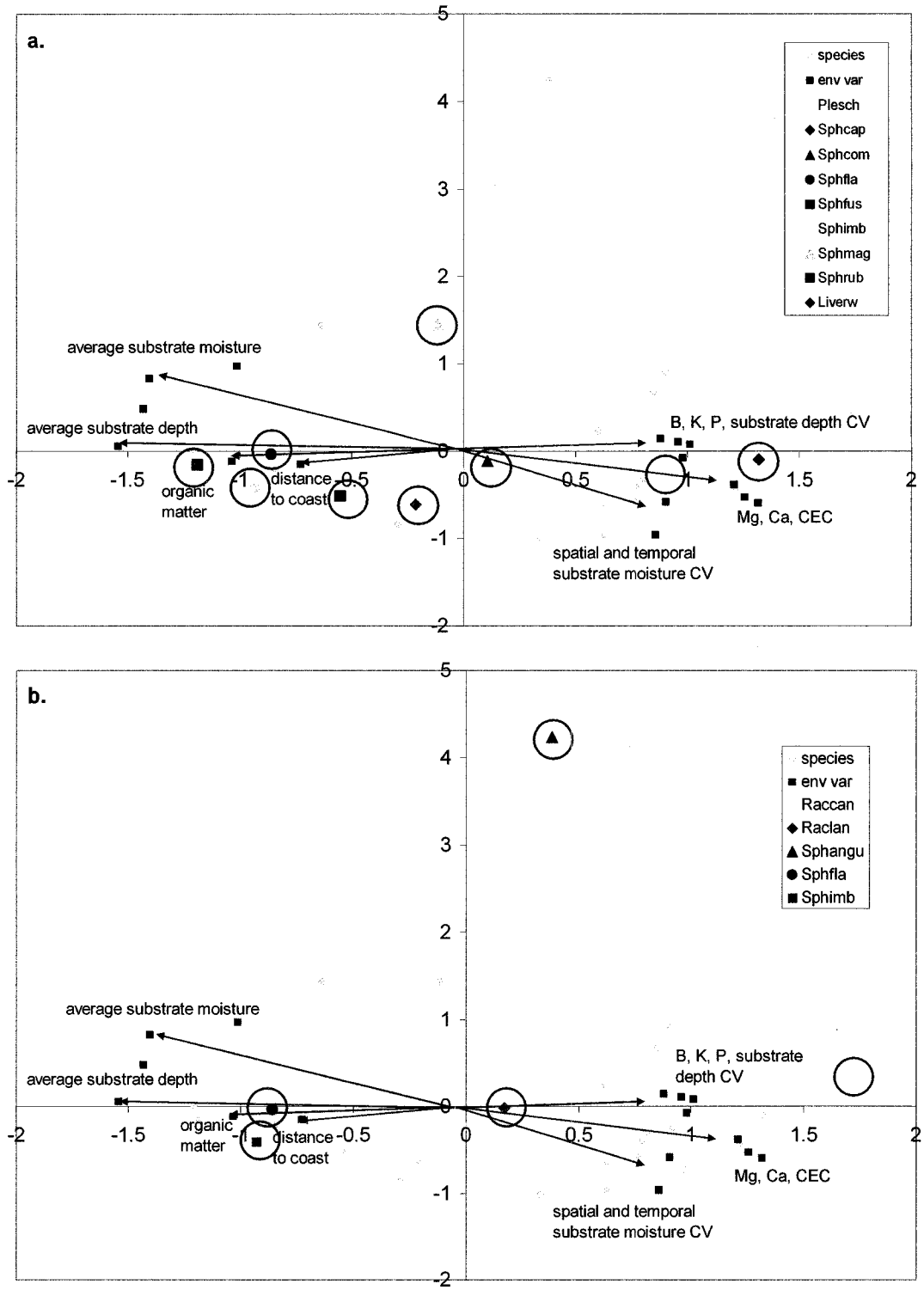



**Figure 16a.** The 9 most common moss species by number of occurrence overlaid on the ordination shown in Figure 15. Red circles highlight the common species. Plesch=*P. schreberi*; Sphcap=*S. capillifolium*; Sphcom=*S. compactum*; Sphfla=S. *flavicomans*; Sphfus=*S. fuscum*; Sphimb=*S. imbricatum*; Sphmag=*S. magellanicum*; Sphrub=*S. rubellum*; Liverw=liverwort (*P. pulcherrimum*). **b.** Rare species overlaid on the ordination shown in Figure 15. Red circles highlight the rare species. Raccan=*R. canescens*; Raclan=*R. lanuginosum*; Sphangu=*S. angustifolium*; Sphfla=*S. flavicomans*; Sphimb=*S. imbricatum*

**Rare species**

The rare species loadings are dispersed along the major hydrological/nutrient/coastal distance gradient of axis 1 (Figure 16b). *Sphagnum angustifolium* loads very strongly on axis 2. It was found in a single plot at Little Anse and is not shared by any other site, which may contribute to its outlying position on the graph.

**Question 3 - How is species richness correlated with environmental factors?**

**Overview of site level species richness**

Peggy's Cove was the most species-rich, with 95 vascular, macrolichen and moss species (Table 14). This number represents only 54% of the total species recorded across all sites. Second in species richness was Canso, with 81 species, followed by Baleine with 78, Chebucto with 72, Little Anse with 68, and Taylor Head with 67.

Canso was the most species-rich in terms of macrolichens, with 26 lichen species. This result is largely an artefact of the high diversity of *Usnea* species (5) found in two tree plots at Canso. If tree lichens are removed from the analysis, Canso's lichen species richness drops to 18 species, which is similar to the lichen richness found at other sites. If both tree and rock lichens are removed, Little Anse and Peggy's Cove emerge as the most lichen rich sites, with 18 species each. Given that Little Anse contains the lowest number of vascular plant and moss species, it is interesting to note that it is comparatively rich in lichen species. Lowest macrolichen richness was found at Taylor Head, with 11 species, the majority of which are *Cladonia* species (Table 14).

Moss species richness was highest at Peggy's Cove, with 16 species, followed closely by Taylor Head with 14. Lowest moss species richness was found at Little Anse

and Chebucto Head, with 9 species each. Compared with vascular and macrolichen species, there was a much smaller range in moss species richness between sites.

The average species richness per plot across all sites was 17 species, which is also the average species richness per plot at Taylor Head. Baleine, Canso and Peggy's Cove had an average species richness of 18 species per plot, and Chebucto Head and Little Anse had 15 and 14 species per plot, respectively (Table 14).

Maximum species richness at the plot level was recorded at Peggy's Cove, where 28 species were recorded at a single plot (PE-08). The maximum species richness at other sites was similar, with a maximum species richness of 25 species at Taylor Head on the low end of the spectrum. With respect to minimum species richness, the minimum number of species recorded in a plot at Canso was 11 species. Chebucto Head, Peggy's Cove and Taylor Head all had plots with only two species present (Table 14).

At the point intersect level, the maximum number of species found to be touching the sampling rod at one time was 10 species. This point fell within plot CA-11, a forest island plot at Canso. Fourteen other points were found to contain eight species. Of these 14 points, eight were also recorded in plot CA-11, one was recorded at Baleine (BA-14), one at Little Anse (LI-20), two at Peggy's Cove (PE-09, PE-17), and two at Taylor Head (TA-08, TA-09).

Table 14. Plot and site-level species richness data for all sites.

| | BA | CA | CH | LI | PE | TA |
|---|---|---|---|---|---|---|
| Max # of spp. per plot | 25 | 27 | 27 | 27 | 28 | 25 |
| Min # of spp per plot | 7 | 11 | 2 | 9 | 2 | 2 |
| Avg # of spp per plot | 18 | 18 | 15 | 14 | 18 | 17 |
| # of vascular spp/site | 51 | 44 | 48 | 39 | 58 | 42 |
| # of lichen spp/site | 16 | 26 | 15 | 20 | 21 | 11 |
| # of moss spp/site | 11 | 11 | 9 | 9 | 16 | 14 |

**Species richness and environmental variables**

In the principal components analysis (PCA) with 26 environmental variables and species richness data for all plant types, only one forest plot, CA-10, was excluded from this analysis due to its atypical vegetation community. Following the removal of this outlier, six principal components were found to have eigenvalues >1, and these components were used as predictors in the multiple regressions on species richness.

The first component in the analysis is positively correlated with pH, P, K, Mg, Na, S, CEC, and negatively correlated with distance to coast (Table 15). The second component is negatively correlated with temporal range and CV in substrate moisture, and positively correlated with spatial substrate moisture minimum. The third component is positively correlated with mean substrate depth and organic matter, and negatively correlated with substrate Fe content. The fourth component is positively correlated with temporal mean substrate moisture, spatial maximum and minimum substrate moisture, and negatively correlated with tatter flag percentage mass loss. The fifth factor is positively associated with spatial range and substrate moisture CV. The sixth factor is correlated positively with rock exposure, average vegetation height, and negatively with substrate depth CV.

Table 15. Principal component analysis (PCA) results for the analysis using all plots (except plot CA-10) and 26 environmental variables.

| | Factor | | | | | |
|---|---|---|---|---|---|---|
| Environmental variable* | 1 | 2 | 3 | 4 | 5 | 6 |
| TEMPTA | -0.203 | 0.504 | 0.011 | 0.805 | 0.019 | 0.119 |
| TEMPTR | -0.112 | -0.835 | 0.105 | 0.257 | -0.059 | -0.095 |
| TEMPTCV | -0.004 | -0.839 | 0.004 | -0.383 | -0.158 | 0.077 |
| SPATTMX | -0.178 | 0.019 | 0.034 | 0.928 | -0.010 | -0.133 |
| SPATTMN | -0.087 | 0.637 | -0.041 | 0.730 | 0.033 | -0.059 |
| SPATTRNG | -0.017 | 0.183 | 0.018 | 0.117 | 0.831 | -0.206 |
| SPATTCV | 0.106 | -0.100 | -0.095 | -0.463 | 0.725 | -0.128 |
| ROCKPC | -0.158 | 0.062 | 0.103 | 0.016 | -0.197 | 0.646 |
| VEGHEIGHT | 0.135 | -0.168 | 0.399 | -0.071 | 0.220 | 0.576 |
| TFML | -0.058 | 0.169 | -0.131 | -0.601 | 0.100 | 0.023 |
| DISTOCOAST | -0.792 | -0.036 | -0.005 | 0.025 | 0.160 | 0.153 |
| ELEVATION | -0.489 | -0.504 | -0.079 | 0.023 | 0.415 | -0.069 |
| SUBSTDEPAV | -0.135 | 0.391 | 0.596 | 0.033 | -0.363 | 0.345 |
| SUBSTDEPRG | 0.372 | -0.113 | 0.348 | -0.291 | 0.247 | -0.099 |
| SUBSTDEPCV | -0.155 | 0.023 | -0.051 | 0.180 | 0.308 | -0.666 |
| ORGMAT | -0.005 | 0.046 | 0.819 | 0.285 | 0.018 | 0.133 |
| PH | 0.647 | 0.044 | -0.100 | 0.255 | -0.091 | -0.220 |
| P | 0.699 | 0.167 | 0.011 | -0.239 | 0.283 | 0.152 |
| K | 0.621 | -0.301 | 0.091 | -0.295 | 0.313 | 0.321 |
| CA | 0.468 | -0.530 | 0.059 | -0.174 | 0.244 | 0.300 |
| MG | 0.861 | -0.267 | -0.104 | -0.221 | 0.009 | 0.058 |
| NA | 0.883 | -0.059 | -0.111 | 0.081 | -0.071 | -0.052 |
| S | 0.771 | 0.294 | -0.209 | -0.046 | 0.154 | 0.241 |
| FE | 0.241 | 0.302 | -0.782 | 0.013 | 0.064 | -0.141 |
| N | 0.563 | 0.214 | 0.368 | -0.237 | 0.028 | -0.043 |
| CEC | 0.695 | -0.426 | 0.058 | -0.220 | 0.153 | 0.337 |
| Variance explained by rotated components | 5.685 | 3.470 | 2.205 | 3.451 | 2.133 | 1.940 |
| % total variance explained | 21.866 | 13.345 | 8.481 | 13.273 | 8.204 | 7.463 |

* TEMPTA=temporal substrate moisture average; TEMPTR=temporal substrate moisture range; TEMPTCV=temporal substrate moisture CV; SPATTMX=max. spatial substrate moisture; SPATTMN=min. spatial substrate moisture; SPATTRNG=spatial substrate moisture range; SPATTCV=spatial substrate moisture CV; ROCKPC=rock percentage cover; VEGHEIGHT=average vegetation height; TFML=tatter flag % mass lost; DISTOCOAST=distance to coast; ELEVATION=elevation; SUBSTDEPAV=substrate depth average; SUBSTDEPRG=substrate depth range; SUBSTDEPCV=substrate depth CV; ORGMAT=organic matter

**Regression of PCA factors with all species richness data**

Stepwise linear regression was performed with the factors from the PCA and with the total species richness data from all plots, with the exception of plot CA-10. Backward and forward stepwise regression produced identical results.

The stepwise regression with total species richness data indicated that factor 1 is negatively correlated with species richness, and that factors 2, 3 and 6 are positively correlated with species richness (Table 16). Richness is thus positively associated with distance to coast, spatial substrate moisture minimum, average substrate depth, organic matter, rock exposure, and vegetation height. Richness is negatively correlated with pH, P, K, Mg, Na, S, CEC, temporal moisture variability, Fe, and substrate depth CV.

Table 16. Backward stepwise regression with all PCA factors showing significant correlations with all species richness data.

| Effect | Coef. | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| Constant | 16.850 | 0.381 | 0.000 | . | 44.239 | 0.000 |
| Factor 1 | -0.718 | 0.383 | -0.160 | 1.000 | -1.876 | 0.063 |
| Factor 2 | 1.035 | 0.383 | 0.231 | 1.000 | 2.705 | 0.008 |
| Factor 3 | 1.444 | 0.383 | 0.322 | 1.000 | 3.775 | 0.000 |
| Factor 6 | 0.773 | 0.383 | 0.172 | 1.000 | 2.020 | 0.046 |

$R^2$=0.183; SE=4.049; df=4; mean-square=119.511; F-ratio=7.291; P=0.00

**Vascular species richness and environmental variables**

Components 2, 3, 4, and 6 were positively correlated with vascular species richness (Table 17). The analysis produced an R-square of 0.295, which indicates that nearly 30% of the variance can be explained by these four factors. The percentage variance explained in this vascular species richness regression is higher than that obtained in the analysis using all species richness data.

The second component is positively correlated with minimum spatial substrate moisture conditions, and negatively associated with temporal substrate moisture variability (range and CV). The third component is positively associated with the average substrate depth and organic matter, and negatively correlated with Fe contents. The fourth component is positively correlated with temporal substrate moisture average, spatial substrate moisture maximum and minimum, and negatively correlated with tatter flag percentage mass loss. The sixth component is positively correlated with rock exposure and average vegetation height, and negatively correlated with substrate depth CV.

Species richness is therefore positively correlated with minimum spatial substrate moisture conditions, average substrate depth, organic matter, temporal substrate moisture average, spatial substrate moisture maximum and minimum, rock exposure, and average vegetation height. Richness was negatively correlated with temporal substrate moisture variability, Fe contents, tatter flag percentage mass loss, and substrate depth CV.

Table 17. Backward stepwise regression with all PCA factors showing significant correlations with vascular plant species richness data.

| Effect | Coef. | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| Constant | 12.619 | 0.301 | 0.000 | . | 41.986 | 0.000 |
| Factor 2 | 0.638 | 0.302 | 0.168 | 1.000 | 2.114 | 0.037 |
| Factor 3 | 1.416 | 0.302 | 0.372 | 1.000 | 4.690 | 0.000 |
| Factor 4 | 0.641 | 0.302 | 0.168 | 1.000 | 2.122 | 0.036 |
| Factor 6 | 1.350 | 0.302 | 0.355 | 1.000 | 4.471 | 0.000 |

$R^2$=0.295; SE=3.195; df=4; mean-square=130.034; F-ratio=12.738; P=0.00

**Lichen species richness and environmental variables**

The same regression was performed using only lichen species richness data. Factors 1, 4 and 6 were all negatively correlated with species richness (Table 18).

Therefore, lichen species richness is positively correlated with distance to coast, tatter flag percentage mass loss and substrate depth CV, and negatively correlated with pH, P, K, Mg, Na, S, CEC, average temporal substrate moisture conditions, spatial substrate moisture maximum and minimum conditions, rock exposure, and average vegetation height. The analysis produced an R-square of 0.158, which indicates that only 16% of the variance in lichen species richness is explained by these three factors.

Table 18. Backward stepwise regression with all PCA factors showing significant correlations with lichen species richness data.

| Effect | Coef. | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| Constant | 2.646 | 0.203 | 0.000 | . | 13.050 | 0.000 |
| Factor 1 | -0.518 | 0.204 | -0.221 | 1.000 | -2.545 | 0.012 |
| Factor 4 | -0.310 | 0.204 | -0.132 | 1.000 | -1.522 | 0.131 |
| Factor 6 | -0.794 | 0.204 | -0.338 | 1.000 | -3.899 | 0.000 |

$R^2$=0.158; SE=2.155; df=3; mean-square=37.155; F-ratio=7.998; P=0.00

**Moss species richness and environmental variables**

Factor 1 is negatively correlated with moss species richness, and Factors 2, 3 and 6 are positively correlated with moss species richness (Table 19). Therefore, moss species richness is positively correlated with the distance to coast, minimum spatial substrate moisture conditions, average substrate depth, organic matter, rock exposure, and average vegetation height, and negatively correlated with pH, P, K, Mg, Na, S, CEC, temporal substrate moisture range and CV, Fe contents, and substrate depth CV. The R-square was 0.194, indicating that 19% of the variance was explained by these four factors.

Table 19 Backward stepwise regression with all PCA factors showing significant correlations with moss species richness data.

| Effect | Coef. | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| Constant | 1.496 | 0.125 | 0.000 | . | 11.995 | 0.000 |
| Factor 1 | -0.474 | 0.125 | -0.321 | 1.000 | -3.787 | 0.000 |
| Factor 2 | 0.366 | 0.125 | 0.248 | 1.000 | 2.923 | 0.004 |
| Factor 3 | 0.306 | 0.125 | 0.207 | 1.000 | 2.440 | 0.016 |
| Factor 6 | 0.186 | 0.125 | 0.126 | 1.000 | 1.485 | 0.140 |

$R^2$=0.194; SE=1.325; df=4; mean-square=13.631; F-ratio=7.760; P=0.00

Table 20. A comparison of the $R^2$ values for all plant types, compiled from Tables 16-19.

| Plant type | $R^2$ |
|---|---|
| All species | 0.183 |
| Vascular plants | 0.295 |
| Lichens | 0.158 |
| Mosses | 0.194 |

## Discussion

### 1. Is there a definitive coastal barren plant community common to all sites?

### Comparisons with other heathland systems

The coastal barrens of Nova Scotia broadly resemble other heathlands in their communities of dominant plant types. Heathlands in the UK and in New England are also dominated by predominantly ericaceous sub-shrubs (Tubbs 1974; Putwain and Gillham 1990; Mitchell *et al.* 1997). Although heathlands in the UK tend to have a high proportion of *Calluna* and *Erica* species, neither of which genera are native to Nova Scotia, many of the other dominant genera are shared. Personal observations of heathland flora in northern Scotland revealed many of the same genera as found on the coastal barrens, including *Empetrum*, *Vaccinium*, *Pleurozium*, *Hylocomium*, and *Pteridium* (Oberndorfer 2006, unpublished data). Coastal barrens in Nova Scotia and Newfoundland are even more closely related in their species composition, with *Empetrum, Kalmia, Scirpus, Rubus, Cladonia*, and *Sphagnum fuscum* strongly represented (Graniero and Price 1999).

In contrast to the heathlands of Europe, grass species are poorly represented in the coastal barrens of Nova Scotia. Invasion of heathlands by grasslands is a prominent conservation concern in parts of Europe (Piessens *et al.* 2006), but does not seem to be occurring in the coastal barrens of Nova Scotia. Coastal barrens in Nova Scotia may not receive the high levels of atmospheric nitrogen from anthropogenic sources to which heathlands in Europe are subject (Terry *et al.* 2004), and this may inhibit grass invasion.

**Common species**

The ten most common species found on the coastal barrens are all wet tolerant species with broad ecological niches (Table 1). Most of the species are all typically found in boreal forest, bog and shrubland habitat. Additionally, most of these species are woody, exhibit vegetative reproduction and have persistent seedbanks, characteristics that increase resistance to extirpation and extinction (Piessens and Hermy 2006), and which favour recolonisation after disturbance.

Although mosses and lichens showed lower global and pairwise separations than vascular plants in the ANOSIM tests, the lichen and moss communities of coastal barrens do not appear to be composed of a key cluster of repeating species that are represented at each site. This result has important conservation significance; namely, that assumptions about the lichen and moss communities of coastal barrens sites cannot be made based on a generalized floristic knowledge of this habitat. Moss and lichen species are site-specific, and comprehensive planning for protected areas must include site-level exploratory work.

The most common moss species found on the coastal barrens was *P. schreberi.* Similarly to the ten most common species, it is also somewhat of a generalist in its habitat type requirements, as it occurs in closed canopy boreal forest, swamps and at the margins of bogs (Crum 1983). It is highly tolerant of nitrogen-poor acidic soils, but is not well-adapted to fire disturbance and may take decades to recover after a burn (Crum 1983). Its abundance in half of the plots at Little Anse and its absence from the other half match what we know of the recent fire history of the site. However, *P. schreberi* was also scarce at Baleine, Chebucto Head and Peggy's Cove, sites with no known recent fire

history. Its relative scarcity at these sites may point to a long absence of nearby forested refugia, which many moss species require for recolonisation (Frego 1996; Fenton and Frego 2005). This observation may indicate that these three coastal barrens have been in a stable, non-forested climax community for many years.

In general, tree species in the coastal barrens are restricted to small dense copses in the middle of shrubland. No tree seedlings were observed in any of the shrub- or crowberry-dominated plots at any of the six sites. This observation corroborates what is known of the extremely slow rate of afforestation in Newfoundland barrens (Meades 1983). Even in the burned section of the Little Anse coastal barren, tree seedlings are not present. As previously discussed, the clonal and competitive strategies of microshrubs, combined with harsh coastal conditions, prevent the germination of tree species even in conditions of increased light resources. Additionally, lichen populations are known to physically and chemically prevent the germination of tree species (Brown and Mikola 1974; Kershaw 1977; Houle and Filion 2003; Sedia and Ehrenfeld 2003).

Coastal barrens have been described as patchworks of distinct habitat types, including bog, forest, rock outcrop, and successional shrubland (Nova Scotia Museum 1997a). However, the broad distribution of a suite of common species throughout the coastal barrens suggests that the patchwork concept is restrictive. Coastal barrens might be better described as having an overlap of conventionally recognised habitat types (bog, shrubland, etc.) that for the most part grade into one another and share many generalist species. Some species may be more commonly found in certain habitat types but are not necessarily exclusive to that habitat type. Forest patches may be the most distinct of these habitat types, having in many cases distinctly different species assemblages from

surrounding bog-barren areas. Indicator species for forest patches include *A. balsamea* and *Usnea* species. Bog areas are best defined by the presence of *Drosera* species, *S. purpurea*, and *S. rubellum* and *S. fuscum*. The most distinctive indicators of barren or "heathland" communities common to a majority of sites are *C. conradii* and *G. baccata*. *Empetrum nigrum* is also distinctive of heathland community but is also found in bogs.

**Rare species** (Table 3)

As noted, rare species of the coastal barrens do not occur in plant communities with a high number of other rare species, which suggests that their continued presence is not linked to glacial refugia. Rare species are embedded in a variety of communities of common species. For example, *S. multiradiata* is found amongst *E. nigrum* , *K. angustifolia* and *J. communis*, the three most common species on the coastal barrens. In terms of conservation, there is therefore no single indicator community which can be targeted for the protection of rare species. However, these rare species are theoretically more likely to persist in stable but stressful shrublands areas where trees are unable to colonise, and where rare plants are not displaced by species with superior dispersal and recruitment abilities. These areas are often at extremes of the soil moisture gradient, at high elevations, or in marine salt spray zones (Latham 2003).

There are also different aspects of rarity on the coastal barrens in terms of a species' local abundance, as well as its regional distribution. For example, *C. tenera* and *V. boreale* are restricted in occurrence to one site each, and are furthermore uncommon at those respective sites. Other rare species, such as *E. eamesii,* are found at few locations, but may be moderately abundant at those sites. *E. eamesii* is in fact locally dominant in

large rocky areas of Chebucto Head and Peggy's Cove. This result suggests that certain rare species, such as *E. eamesii*, are better adapted to the conditions present on coastal barrens than to conditions present in other habitat types, and could be considered endemic to the coastal barrens. Their rarity is therefore linked to the relative scarcity of coastal barrens in Nova Scotia. Conversely, species that are both rare in terms of number of sites and rare in abundance may be relics of another habitat type, are possibly unsuited to current coastal barren conditions, and may have poor seed dispersal in these conditions. They may have an "extinction debt" (Tillman *et al.* 1994, Hanski and Ovaskainen 2002) and their long-term persistence in the coastal barrens is less certain.

It is theorised that age and stability of heathlands are correlated with number of rare species present, although more evidence is needed before this theory can be accepted (Latham 2003). The presence of rare species on the coastal barrens may therefore reflect the amount of time these unforested habitat types have persisted.

**Site comparisons**

The correspondence analysis with all plots, with outliers removed, illustrates the degree of overlap between sites (Figure 2a). If all sites had the same species assemblages, we would expect that plots from all sites would be mixed together on the axes. The positive end of axis 1 illustrates this type of pattern, in which plots from several sites overlap. These plots all occur in areas with dominant bog conditions, indicating that community structure in coastal barren bog communities may be relatively constant across sites.

The majority of the plots, however, separate out according to site. Baleine and Little Anse clearly differ in their plant communities from any other site, and the results of the MDS confirm this observation. Little Anse is unique in being the only site with a known recent disturbance history. Past fire and grazing activities may be responsible for the release of such species as *S. tridentata* and *M. canadense*, both of which were among a list of the ten most abundant species at Little Anse, and neither of which figured prominently at other coastal barren sites. In particular, populations of *M. canadense* are known to increase after burning due to their persistent and heat-tolerant rhizomes (Swan 1970), and *S. tridentata* is also known to persist after disturbance thanks to its rhizomatous growth. Both of these species may have taken advantage of increased light conditions and reduced competition in the aftermath of a fire.

The CA and ANOSIM results indicated that Baleine and Little Anse are more similar to each other than to any other sites. There are a number of possible explanations for the similarities between these two sites: 1) they are the only two sites from Cape Breton Island and may share similar seed sources and climatic conditions; 2) topographically, they are similarly lacking in variability; 3) exposed rock and tree cover is extremely sparse and microhabitat diversity for rock and epiphytic lichen species is limited; and 4) both sites are in areas with a long history of human habitation and disturbance.

The vegetation communities at Taylor Head appear to be more consistently homogeneous throughout the site than at other coastal barrens. Several plots at Taylor Head that are close in real space load close to each other in the correspondence analysis. This pattern indicates that spatial autocorrelation may have an influence on the

community structure of nearby plots. Spatial autocorrelation may be affected by macrotopography, as flat areas with little variation in elevation will be more homogeneous in their slope, exposure and possibly hydrology. It is theorised that environmental heterogeneity is correlated with the number of available niches (Silvertown 2004), which, in addition to chance arrival and dispersal, may be correlated with community structure. However, it is clear that spatial autocorrelation does not account for the majority of plot loadings in the correspondence analysis, as most real-space neighbouring plots do not graphically load next to each other.

The CA and ANOSIM results confirm that Canso and Chebucto Head share more similarities in vegetation communities than of any of the other north-south sites (Table 9). In the literature, Canso and Chebucto Head are described as having similar plant communities, which is generally attributed to their granitic bedrock (Nova Scotia Museum 1997b). There also appear to be small ecological differences among Taylor Head, Chebucto Head and Peggy's Cove, the three southernmost sites. Considering the bog plots that load at the positive end of axis 1 and the rock and tall shrub plots that were removed as outliers, Peggy's Cove has high variability in the types of vegetation communities that are found in its plots. Again, this may be due to high environmental heterogeneity resulting from its varied macrotopography.

**Correspondence analysis using all species**

Species loading at the extremes of the axes are generally uncommon in the coastal barrens. Some of these species are so distantly removed from the main cluster of species that they can be considered to occupy a separate micro-habitat within a coastal barren.

Substrate type is a key factor affecting the distribution of some of these species, such as the rock lichens *L. papulosa* and *M. stygia*, which are dependent on large outcrops of bedrock (Brodo *et al.* 2001). Likewise, the establishment and persistence of *A. balsamea,* and the community of lichens and mosses with which it is found, is possibly dependent on pockets of glacial till. Judging by the low level of tree cover on the coastal barrens, such conditions appear to be scarcely available.

Rare species are found in a more diverse range of substrate moisture conditions than common species. Additionally, they are correlated with plant communities that have average to low vegetation height, in the types of areas identified by Latham as persistently under stress and consequently free of trees or processes of succession (2003). If it is found that areas of coastal barren are slowly undergoing a process of succession from microshrubs to taller shrubs and trees, there may be conservation implications for the continued existence of these rare species. Likewise, a shift in hydrology that discourages variable substrate moisture conditions may also adversely affect populations of rare species. However, it appears that plots containing rare species are located in permanent communities of highly-stressed microshrubs where succession is unlikely in the foreseeable future.

**Correspondence analysis using equally-weighted species**

The results of the CA using presence-absence data suggest that sites differ not only in relative abundance of species, but in species composition (Figure 4). Species composition alone is sufficiently different to differentiate sites. The fact that the correspondence analysis with species abundance data produces more outliers

demonstrates that differences in species abundance magnifies differences in species composition between sites.

**Correspondence analysis using plant-type species data**

Vascular plants

The results of the CA and ANOSIM using only vascular plant data (Figure 5, Table 6, Table 9) indicate that differences among sites are better resolved when lichen and moss data are excluded, and that plant communities of the coastal barrens are not only dominated by vascular species, but that site separation is highly based on differences among those vascular species. These results again suggest that sites are more different in their vascular plant communities than in their lichen and moss communities. However, one must be cautious about inferring site similarities and differences among sites based on vascular plant data alone, as it does not address site-level differences in lichen and moss communities.

Lichens

The lichen communities at Canso, Chebucto Head and Peggy's Cove appear to be different from the lichen communities at the other sites, and to have greater variability in their lichen communities, as evidenced by the large amount of spread in their plot loadings. Lichen diversity has been shown to be correlated with the structural complexity of habitat types (Lesica *et al.* 1991; Crites and Dale 1998; Uliczka and Angelstam 2000; Pipp *et al.* 2001). Therefore, sites with greater availability of microsites, including substrate types, should have richer lichen communities.

The ANOSIM results show lower separation distances for the lichens than for all species and vascular species (Table 9), indicating that lichen communities are more similar among the sites than are vascular plant communities. Furthermore, the inter-site similarities and dissimilarities identified do not follow the same pattern as the vascular plant and all species ANOSIM, suggesting that the structure of lichen communities is not directly linked with the structure of vascular plant communities, despite the fact that many lichens are epiphytic on vascular plants. These differences indicate that substrate type may be correlated with the types of lichen species present at each site. Consequently, sites may be more similar in their lichen communities if they contain a similar diversity of habitat types (e.g. rock outcrops, bogs, etc.).

Mosses

Sites are more similar in their moss communities than in their lichen or vascular plant communities (Figure 8, Table 9). The correspondence analysis using moss data is not useful for resolving site differences; rather, the analysis shows only the division of forest and hydrophilic species along a hydrological gradient. While it is apparent that different moss species in the coastal barrens are correlated with different substrate moisture conditions, the fact that these substrate moisture conditions are to some degree present at all sites does not make moss community composition an effective tool for separating sites. It does, however, indicate that conservation efforts aimed at safeguarding moss diversity should seek to protect a broad range of environmental conditions. Protecting microsite diversity is one component of establishing bryophyte refugia that has already been proposed by other authors (Fenton and Frego 2004).

## 2. Which environmental factors are correlated with plant community structure?

### Species and environmental factors

Distance to the coast and variables correlated with this factor play an important role in structuring species assemblages on the coastal barrens. In review, species farther from the coast are found in conditions of high average substrate depth, invariably moist substrate conditions, and substrates that are rich in organic matter. The opposite end of this gradient is characterized by nearshore conditions of variable substrate depth and variable substrate moisture content, as well as by elevated concentrations of Na, Ca, Mg, and a high CEC (Figure 10). These elevated substrate cations are presumed to be the result of salt spray (Bates 1975). However, most of the plots at the inland end of the gradient are in bogs, which are known to be nutrient poor (van Breeman 1995). Thus, prevailing bog substrate conditions rather than reduced salt spray may be responsible for low nutrient levels at inland plots. Incidentally, salt spray was not absent from inshore areas: aluminium plot identification tags located 400 m inland were found coated in salt crystals.

The other major environmental gradient affecting species communities is average vegetation height (Figure 10). The majority of species loadings do not fall along this gradient, but a specific cohort of forest and tall shrubland species does. Conditions in forest plots, including reduced competition from shrubs, reduced light levels and increased humidity, may permit forest understory species such as *L. borealis*, *B. velutinum* and *Oclemena acuminata*. It is unknown why some clonal forest understory

species, such as *C. canadensis* and *M. canadense*, are prevalent in short microshrub communities of *V. angustifolium*, *K. angustifolia* and *G. baccata,* whereas other clonal forest species, such as *L. borealis*, are absent. It may be that salt tolerance or some other factor limits the success of these other clonal forest species

Given that many moss species are intolerant of salt and are not abundant in nearshore areas (Bates 1975; Wilcox 1984), and that *Sphagnum* species are typically associated with acidic environments, it is unusual to observe *S. angustifolium* loading so strongly on the nearshore, high pH end of the gradient. This observation can be explained by noting that *S. angustifolium*, which was found in a single plot at a single site, is loading next to another dominant species in that plot, *G. hispidula*. In this case, species co-occurrence data is likely to have more of an effect than environmental data on the species loading.

Rare species are found in all conditions of substrate moisture, substrate nutrients and substrate depth, both inland and along the coast (Figure 3b). Slightly more rare vascular plants load closer to the coast and its associated high exposure and salt spray zone, which is historically where many of today's rare species were likely found in pre-European times (Motzkin and Foster 2002). As several of the rare *Sphagnum* mosses are associated with inland areas, it is recommended that inland areas of coastal barrens should also be protected.

All rare species load at a similarly low level of community vegetation height (Figure 11b). As mentioned with respect to the correspondence analyses, rare species do not appear to tolerate moderate to high vegetation height. Tall vegetation height on the coastal barrens is not necessarily an indication of succession, however. It is more likely

that most areas with tall shrubs reflect pockets of higher productivity rather than the time elapsed since disturbance. Although succession of some coastal barrens to tall shrubland and forest may pose a threat to the existence of rare coastal barren species, much of the microshrub communities are likely stable and will continue to contain rare species if current environmental conditions persist (Latham 2003).

Results of the partial canonical correspondence analysis indicate that variation explained by the sites (the covariables) is less than the variation explained by the environmental variables. This being the case, we can state that the effect of environmental variables in separating out species according to gradients is more important than the effect of site and its corresponding spatial autocorrelation. Community structure is therefore not entirely or even largely dependent on spatial factors (Palmer 2006).

**Canonical correspondence analysis: plant type data**

Vascular plants

Given the similarities between the CCA with all species data (Figure 10) and the CCA with vascular plant data only (Figure 12), it is clear that the CA pattern is dominated by vascular species. The number of vascular species and the abundance of these species play a proportionately powerful role in distinguishing vegetation communities at the different sites.

Lichens

Vegetation height, and the inversely related substrate moisture content, are correlated with lichen community structure (Figure 13). Site-level vegetation height gradients encourage a range of species: taller vegetation supports *Usnea* species, *B. trichodes*, and *P. squarrosa,* and intermediate shrub height supports *Cladonia* species. Whereas more vascular species occur in areas of high substrate moisture content, lichen species load away from consistently wet environments. Changes in the hydrology of a site will therefore potentially affect lichen species as well as vascular species, but possibly in opposite ways.

Elevation, substrate depth variability and rock exposure are also correlated with lichen community structure (Figure 13). Similarly to vegetation height gradients, rock exposure is shown to increase the types of substrates available to lichens in this study. It is interesting to note that variable substrate depth (which includes a variety of substrates, such as rock, microshrub and tree) also appears to be important in providing niches for a variety of lichen species, especially given that variable substrate depth was not strongly associated with many vascular species. Variable substrate depth is correlated with substrate moisture variability, a condition which may allow cryptobiotic lichens to persist where vascular plants and mosses cannot.

Most common lichen species, the majority of which are *Cladonia* species, load in moderate environmental conditions, although some species favour more extreme conditions of exposed rock or tall vegetation (Figure 14). In general, it can be said that all sites contain a range of conditions suitable for colonisation by common lichen species, including moderate environmental conditions, as well as rocky and forest habitat.

Mosses

Moss species loadings are dispersed along the entire length of the dominant environmental gradient (substrate moisture conditions) (Figure 15), which suggests that moss species appear to make fuller use of a wide range of substrate moisture conditions as compared to lichens and vascular species. Unlike the cluster formed by common vascular species, common moss species are also evenly spread along this primary environmental gradient (Figure 16a). This loading pattern suggests that common species are supported at all sites by a diverse set of moisture conditions. Although work in forested systems has shown that substrate diversity is an important factor in ensuring bryophyte diversity (Fenton and Frego 2004), it appears that hydrological gradients are also critical to promoting moss diversity in the coastal barrens. It has been proposed that differences in moisture conditions at a small scale may have large effects on bryophyte communities (Grytnes *et al.* 2006). Rare moss species exhibit the same loading spread over the same environmental gradient, and they are subject to the same conservation considerations as common moss species (Figure 16b).

**3. How is species richness correlated with environmental factors?**

**General overview**

In general, more species load closer to the inland bog conditions than to the nearshore conditions (Figure 10). Although nearshore conditions of spatial and temporal substrate moisture variability and substrate depth variability theoretically create more potential niches (Tilman 1982; Tilman 1994; Silvertown *et al.* 1999; Chesson 2000), it is not apparent that these theorised niches are being exploited. The observation that most

species load closer to inland conditions of reduced substrate moisture and substrate depth variability indicates that this environment may ultimately be less stressful for plants. Additionally, the growth and function of many plants are adversely affected by salt (Slayter 1967), which is prevalent in nearshore conditions.

Inland conditions support plant communities that contain a diversity of plant types. For example, the most strongly loading species on the inland gradient include two moss species, three different lichen genera, a tree species, and representatives from the Cyperaceae, Juncaceae and Ericaceae. In contrast, nearshore communities are devoid of moss species, and instead dominated by clonal species such as *E. eamesii* and *J. horizontalis*. The low wind-evading growth forms of these plants may aid in persistence in these nearshore conditions, where drying action and tissue damage is a threat (Grace 1977).

The highest total species richness at the site level was found at Peggy's Cove (Table 14). This site contains units of tall shrubs, rock, bog, and trees that provide a wide suite of conditions for diverse species. Environmental heterogeneity has been shown to be correlated with species richness (Lundholm and Larson 2003b), and this heterogeneity likely accounts for the high overall richness of different plant types at Peggy's Cove. This theory is supported by the CCA results indicating the various environmental gradients along which different plant types occur.

The greatest species richness at the plot level was also found at Peggy's Cove, with plot PE-08 containing 28 species (Table 14). When compared with the 88 species found in the same unit area in a dry steppe community (Kull and Zobel 1991), this level of species richness appears relatively low. What little literature exists on the coastal

barrens of Nova Scotia typically refers to this system as being low in diversity (Nova Scotia Museum 1997a). However, when one considers that many of the coastal barrens species are clonal shrubs, the more salient feature of these sites may be the high density of these different shrub species.

All six sites have plots represented in a list of the top ten species rich plots. These plots typically contain the dominant ericaceous shrubs and generalist vascular plants, and have slightly shorter than average vegetation height. However, the majority of plots with high point-intersect level richness are forest plots at Canso. This result is likely due to the high amount of canopy cover and high percentage cover of epiphytic lichens, which were consistently recorded for every point in the plot.

These same forest plots were responsible for much of the high site-level lichen diversity recorded at Canso. Once forest and rock lichens are removed from the analysis, Little Anse is shown to have high lichen species richness, which is possibly linked to its fire and grazing history. There is evidence to suggest that high lichen richness is correlated with open canopied *Calluna* stands in Europe, in areas with low soil productivity, bare soil, and frequent grazing (Sanderson 1996). Lichen communities are damaged by fire, but these fires are also responsible for the development of new lichen-rich communities (Sanderson 1996). Reductions in disturbance frequency and the consequent increase in the closure of shrub canopy on the coastal barrens may therefore adversely affect the total richness of lichen communities. Conversely, fire disturbance may not promote vascular species richness, as Little Anse is very poor in vascular species. Certainly the absence of many rare vascular species at Little Anse is in keeping

with the relationship between shrubland age/stability and number of rare species that has been proposed by Latham (2003).

**Species richness and environmental variables**

All species and vascular plants

Several patterns emerge in the PCA and in the regression with all species data (Table 16) that are inconsistent with the species richness literature. Unlike the positive correlation between nutrient levels and species richness in other habitats (Grime 1979; Roem and Berendes 2000), species richness on the coastal barrens is negatively associated with nutrient levels, including Na, as shown by the negative correlation with the coastal effects component (component 1; Table 16). These results may also reflect the increased richness in inland areas, away from stressful coastal conditions, where bog-like and nutrient-poor conditions dominate. Evidence for this hypothesis is also found in the strong correlation of species richness with distance to coast.

Likewise, species richness is negatively correlated with pH, which does not agree with richness-pH relationships in most other habitats (Grime 1979; Houdijk *et al.* 1993; Roelofs *et al.* 1996; Schuster and Diekmann 2003). The strength of the pH-species richness correlation in the regression is weaker than the correlation with distance to coast, however, which may play a more dominant role in controlling for species richness. Species richness is also correlated with a productivity component (component 3), including deeper substrate, higher organic matter and taller vegetation, conditions which are also associated with inland bogs. Bogs are traditionally considered a species-poor

habitat, but appear relatively rich when compared with impoverished nearshore coastal communities.

Species richness is negatively correlated with temporal substrate moisture variability in the temporal substrate moisture variability component (component 2) and substrate depth variability in the substrate fertility component (component 6), which agrees with previous work on alvar plant communities (Lundholm and Larson 2003a). High variability in environmental conditions is stressful for plants, and does not appear to provide accessible spatial and/or temporal niches. As in previous analyses, correlates of all species and vascular species richness are similar, once again demonstrating that analyses are dominated by vascular plant data.

Lichens

Lichen richness is correlated with different environmental variables than vascular plant richness, and is often inversely correlated with any shared causal environmental variables. Lichens exploit different niches than vascular plants and are able to take advantage of conditions that vascular plants consider stressful, such as variable substrate depth and exposure to wind (Table 18). Although many lichen species are epiphytic on shrubs and trees, lichen richness on the coastal barrens is negatively correlated with vegetation height. This result is in agreement with lichen richness studies in the UK (Sanderson 1996).

Mosses

Moss species richness is correlated with the same variables as species richness for all plant types. Moss species richness increases with high substrate moisture conditions (Table 19), which bryophytes require for basic functions and propagation, as they lack vascular tissue. Conversely, temporal fluctuations in water availability were negatively correlated with moss species richness for the species surveyed. Moss species richness is positively correlated with substrate depth, organic matter contents and vegetation height, conditions which may all promote moisture retention. Moss species richness is negatively correlated with pH, which reflects the high number of species found in bogs. Finally, moss species richness is highest away from the coast, which is consistent with the salt intolerance of most moss species, as stated previously.

**Summary**

Coastal barrens in Nova Scotia are an extremely heterogeneous habitat type supporting a wide variety of plant communities. Sites are distinct in both species composition and abundance. Certain abundant species are shared among sites, but many rare species are not. As communities and rare-species are site-specific, it is difficult to base conservation planning decisions on a generalised knowledge of the coastal barrens. It is recommended that the planning of protected areas be based on as much local field work as possible in order to accurately describe site-specific plant communities and direct protection efforts accordingly.

Rare vascular species of the coastal barrens appear to require stable microshrub communities of relatively common species in areas of chronic coastal stress. Rare

species may be correlated with the age and stability of coastal barren areas, but more research is needed on this subject. The succession of coastal barrens to tall shrub-forest communities poses a potential threat to the continued presence of these rare species. Changes in the hydrological gradient to drier than average conditions may also pose a threat to rare vascular species.

Lichen species appear to be correlated with drier average substrate moisture conditions than vascular plants and mosses, and their richness is correlated with variability in environmental conditions, such as substrate depth. In this way, lichens are able to exploit conditions not conducive to vascular or moss species richness. Lichen richness is also correlated with a diversity of substrate types. Fire disturbance may also promote lichen species richness over the long term, although it possibly has a detrimental impact on richness in the short term. Information on crustose lichen communities on the coastal barrens is still lacking, and requires research.

Much more work on bryophyte distribution is required on the coastal barrens, including a thorough review of liverworts and hornworts. It is currently difficult to make conservation recommendations for either mosses or lichens given our lack of knowledge about rare species and their distribution. Moss species' richness appears to be correlated with hydrological diversity at the site level. In this case, protecting areas with a wide range of moisture conditions will benefit coastal barren vascular plants and mosses (greater richness in wetter areas), as well as lichens (greater richness in drier and more variable areas).

As mentioned, stressful coastal conditions benefit populations of rare vascular plants. However, given that moss species richness is greater away from the coast, coastal

barren protected areas should be extended inland to ensure greater protection for these moss species. Protecting inland areas will also protect vascular plant richness, which, with the exception of rare species, is greatest away from the coast.

Based on the findings of this research, it is strongly recommended that Baleine and Peggy's Cove be afforded formal protected areas status. These two large sites are extremely important repositories of rare species, and are also highly species-rich. Peggy's Cove, due to its proximity to Halifax and its popularity with tourists, is particularly at risk without formal protection. Baleine has almost three times more rare species than other site and may contain yet more rare species. Both of these sites would be ecologically important additions to the provincial Nature Reserve system.

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**Appendix A.** A complete list of the 105 vascular species found at the plot level across six coastal barren sites (Peggy's Cove, Chebucto Head, Taylor Head, Canso, Little Anse, and Baleine). SRANKs (where available) are from the Atlantic Canada Conservation Data Centre (2006). Columns 4-9 indicate the number of times a species was found at a site. Column 10 indicates how many sites contained each species. The last column indicates the total number of times each species was encountered during sampling across all six sites

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Abies balsamea* | Pinacea | S5 | 0 | 72 | 0 | 0 | 0 | 0 | 1 | 72 |
| *Alnus viridis* | Betulaceae | S5 | 0 | 38 | 36 | 0 | 7 | 4 | 3 | 85 |
| *Amelanchier bartramiana* | Rosaceae | S5 | 0 | 3 | 1 | 0 | 0 | 0 | 2 | 4 |
| *Amelanchier stolonifera* | Roasaceae | S3? | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 2 |
| *Andromeda polifolia* | Ericaceae | S5 | 25 | 0 | 0 | 0 | 0 | 0 | 1 | 25 |
| *Aralia nudicaulis* | Araliaceae | S5 | 0 | 106 | 12 | 0 | 4 | 0 | 3 | 122 |
| *Arctostaphylos uva-ursi* | Ericaceae | S4 | 0 | 0 | 0 | 0 | 22 | 0 | 1 | 22 |
| *Calamagrostis pickeringii* | Poaceae | S4S5 | 32 | 0 | 11 | 0 | 44 | 0 | 3 | 87 |
| *Carex echinata* | Cyperaceae | S5 | 0 | 0 | 0 | 1 | 17 | 0 | 2 | 18 |
| *Carex exilis* | Cyperaceae | S4 | 0 | 0 | 0 | 0 | 21 | 0 | 1 | 21 |
| *Carex folliculata* | Cyperaceae | S5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Carex nigra* | Cyperaceae | S5 | 49 | 0 | 0 | 124 | 0 | 6 | 3 | 179 |
| *Carex paleacea* | Cyperaceae | S5 | 23 | 0 | 0 | 0 | 0 | 0 | 1 | 23 |
| *Carex pauciflora* | Cyperaceae | S4S5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Carex rariflora* | Cyperaceae | S1 | 18 | 0 | 0 | 0 | 0 | 0 | 1 | 18 |
| *Carex tenera* | Cyperaceae | S1S2 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Carex trisperma* | Cyperaceae | S5 | 26 | 0 | 12 | 0 | 26 | 48 | 4 | 112 |
| *Cerastium fontanum* | Caryophyllaceae | SE | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Chamaedaphne calyculata* | Ericaceae | S5 | 41 | 0 | 0 | 0 | 43 | 32 | 3 | 116 |
| *Chamerion angustifolium* | Onagraceae | S5 | 0 | 16 | 0 | 0 | 0 | 0 | 1 | 16 |
| *Clintonia borealis* | Liliaceae | S5 | 1 | 21 | 2 | 0 | 14 | 1 | 5 | 39 |
| *Coptis trifolia* | Ranunculaceae | S5 | 0 | 0 | 4 | 9 | 9 | 2 | 4 | 24 |
| *Corema conradii* | Empetraceae | S4 | 0 | 119 | 113 | 0 | 71 | 0 | 3 | 303 |
| *Cornus canadensis* | Cornaceae | S5 | 17 | 75 | 19 | 38 | 6 | 24 | 6 | 179 |
| *Danthonia spicata* | Poaceae | S5 | 0 | 0 | 0 | 56 | 0 | 0 | 1 | 56 |
| *Deschampsia flexuosa* | Poaceae | S5 | 0 | 31 | 0 | 0 | 13 | 0 | 2 | 44 |

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Doellingeria umbellata* | Asteraceae | S5 | 0 | 15 | 0 | 0 | 0 | 0 | 1 | 15 |
| *Drosera intermedia* | Droseraceae | S5 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Drosera rotundifolia* | Droseraceae | S5 | 15 | 0 | 28 | 5 | 5 | 5 | 5 | 58 |
| *Dryopteris carthusiana* | Dryopteridaceae | S5 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Empetrum eamesii* | Empetraceae | S2S3 | 0 | 0 | 29 | 0 | 0 | 0 | 1 | 29 |
| *Empetrum nigrum* | Empetraceae | S5 | 521 | 0 | 63 | 400 | 107 | 230 | 5 | 1321 |
| *Epigaea repens* | Ericaceae | S5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Eriophorum vaginatum* | Cyperaceae | S5 | 6 | 0 | 0 | 0 | 0 | 2 | 2 | 8 |
| *Eriophorum virginicum* | Cyperaceae | S5 | 0 | 0 | 0 | 1 | 1 | 3 | 3 | 5 |
| *Euphrasia randii* | Scrophulariaceae | S4 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Festuca rubra* | Poaceae | S5 | 25 | 3 | 10 | 0 | 0 | 0 | 3 | 38 |
| *Gaultheria hispidula* | Ericaceae | S5 | 0 | 0 | 0 | 15 | 0 | 0 | 1 | 15 |
| *Gaultheria procumbens* | Ericaceae | S5 | 4 | 113 | 15 | 62 | 27 | 26 | 6 | 247 |
| *Gaylussacia baccata* | Ericaceae | S5 | 0 | 148 | 197 | 0 | 174 | 122 | 4 | 641 |
| *Gaylussacia dumosa* | Ericaceae | S4 | 0 | 0 | 46 | 0 | 129 | 62 | 3 | 237 |
| *Ilex glabra* | Aquifoliaceae | S5 | 0 | 4 | 0 | 0 | 27 | 0 | 2 | 31 |
| *Ilex verticillata* | Aquifoliaceae | S5 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 4 |
| *Iris setosa* | Iridaceae | S4 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Iris versicolor* | Iridaceae | S5 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Juncus sp.* | Juncaceae | . | 7 | 0 | 0 | 0 | 0 | 0 | 1 | 7 |
| *Juniperus communis* | Cupressaceae | S5 | 120 | 2 | 247 | 77 | 199 | 243 | 6 | 888 |
| *Juniperus horizontalis* | Cupressaceae | S4 | 14 | 0 | 35 | 0 | 4 | 0 | 3 | 53 |
| *Kalmia angustifolia* | Ericaceae | S5 | 110 | 280 | 135 | 12 | 88 | 199 | 6 | 824 |
| *Kalmia polifolia* | Ericaceae | S5 | 18 | 0 | 16 | 0 | 12 | 9 | 4 | 55 |
| *Larix laricina* | Pinacea | S5 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| *Linnaea borealis* | Caprifoliaceae | S5 | 1 | 17 | 0 | 2 | 0 | 0 | 3 | 20 |
| *Lonicera villosa* | Caprifoliaceae | S4S4 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Lycopodium annotinum* | Lycopodiaceae | S5 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Lycopodium obscurum* | Lycopodiaceae | S5 | 0 | 0 | 6 | 0 | 0 | 0 | 1 | 6 |
| *Maianthemum canadense* | Liliaceae | S5 | 27 | 59 | 13 | 73 | 14 | 19 | 6 | 205 |
| *Melampyrum lineare* | Scrophulariaceae | S5 | 0 | 1 | 0 | 0 | 1 | 3 | 3 | 5 |

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mitchella repens* | Rubiaceae | S5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Morella pensylvanica* | Myricaceae | S5 | 15 | 78 | 43 | 30 | 24 | 63 | 6 | 253 |
| *Myrica gale* | Myricaceae | S5 | 43 | 1 | 5 | 5 | 22 | 0 | 5 | 76 |
| *Nemopanthus mucronatus* | Aquifoliaceae | S5 | 0 | 7 | 6 | 0 | 19 | 20 | 4 | 52 |
| *Oclemena acuminata* | Asteraceae | S5 | 0 | 13 | 4 | 1 | 4 | 1 | 5 | 23 |
| *Oclemena nemoralis* | Asteraceae | S5 | 6 | 0 | 1 | 3 | 18 | 0 | 4 | 28 |
| *Oclemena x blakei* | Asteraceae | HYB | 11 | 0 | 0 | 0 | 0 | 0 | 1 | 11 |
| *Osmunda cinnamomea* | Osmundaceae | S5 | 10 | 161 | 0 | 75 | 27 | 12 | 5 | 285 |
| *Photinia melanocarpa* | Rosaceae | S5 | 74 | 75 | 39 | 15 | 8 | 43 | 6 | 254 |
| *Picea glauca* | Pinacea | S5 | 0 | 0 | 0 | 0 | 45 | 6 | 2 | 51 |
| *Picea mariana* | Pinacea | S5 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 |
| *Picea rubens* | Pinacea | S5 | 0 | 0 | 0 | 0 | 41 | 47 | 2 | 88 |
| *Plantago maritima* | Plantaginaceae | S5 | 5 | 0 | 0 | 0 | 0 | 6 | 2 | 11 |
| *Poa palustris* | Poaceae | S5 | 0 | 14 | 0 | 0 | 0 | 0 | 1 | 14 |
| *Prenanthes nana* | Asteraceae | S2? | 10 | 0 | 0 | 0 | 0 | 0 | 1 | 10 |
| *Prenanthes trifoliolata* | Asteraceae | S5 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 2 |
| *Prunus pensylvanica* | Rosaceae | S5 | 0 | 37 | 0 | 0 | 0 | 0 | 1 | 37 |
| *Pteridium aquilinum* | Dennstaedtiaceae | S5 | 0 | 50 | 28 | 0 | 29 | 3 | 4 | 110 |
| *Rhodedendron groenlandicum* | Ericaceae | S5 | 59 | 81 | 31 | 15 | 20 | 91 | 6 | 297 |
| *Rhododendron canadense* | Ericaceae | S5 | 0 | 57 | 21 | 3 | 16 | 5 | 5 | 102 |
| *Rhynchospora alba* | Cyperaceae | S5 | 9 | 0 | 0 | 0 | 20 | 0 | 2 | 29 |
| *Ribes sp.* | Grossulariaceae | . | 0 | 6 | 0 | 0 | 0 | 0 | 1 | 6 |
| *Rosa carolina* | Rosaceae | S4S5 | 8 | 7 | 2 | 0 | 0 | 0 | 3 | 17 |
| *Rosa nitida* | Rosaceae | S4 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 2 |
| *Rubus canadensis* | Rosaceae | S5 | 0 | 0 | 0 | 0 | 13 | 0 | 1 | 13 |
| *Rubus chamaemorus* | Rosaceae | S4 | 42 | 0 | 21 | 0 | 1 | 16 | 4 | 80 |
| *Rubus hispidus* | Rosaceae | S5 | 0 | 0 | 0 | 0 | 9 | 0 | 1 | 9 |
| *Rubus idaeus* | Rosaceae | S5 | 0 | 18 | 0 | 0 | 0 | 0 | 1 | 18 |
| *Rubus pubescens* | Rosaceae | S5 | 0 | 4 | 1 | 9 | 0 | 0 | 3 | 14 |
| *Rubus setosus* | Rosaceae | S4? | 17 | 0 | 3 | 0 | 0 | 0 | 2 | 20 |
| *Sarracenia purpurea* | Sarraceniaceae | S5 | 1 | 0 | 3 | 2 | 16 | 6 | 5 | 28 |

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Sibbaldiopsis tridentata* | Rosaceae | S5 | 25 | 0 | 7 | 159 | 2 | 2 | 5 | 195 |
| *Solidago multiradiata* | Asteraceae | S1S2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Solidago puberula* | Asteraceae | S5 | 1 | 0 | 0 | 1 | 5 | 0 | 3 | 7 |
| *Solidago uliginosa* | Asteraceae | S5 | 0 | 12 | 0 | 6 | 1 | 8 | 4 | 27 |
| *Spiranthes lacera* | Orchidaceae | S5 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Symphyotrichum novi-belgii* | Asteraceae | S5 | 18 | 0 | 0 | 6 | 3 | 0 | 3 | 27 |
| *Thalictrum pubescens* | Ranunculaceae | S5 | 0 | 8 | 0 | 0 | 0 | 0 | 1 | 8 |
| *Thelypteris noveboracensis* | Thelypteridaceae | S5 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Trichophorum caespitosum* | Cyperaceae | S5 | 75 | 0 | 25 | 0 | 23 | 34 | 4 | 157 |
| *Trientalis borealis* | Primulaceae | S5 | 18 | 15 | 7 | 5 | 17 | 7 | 6 | 69 |
| *Vaccinium angustifolium* | Ericaceae | S5 | 45 | 137 | 66 | 164 | 69 | 94 | 6 | 575 |
| *Vaccinium boreale* | Ericaceae | S2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Vaccinium macrocarpon* | Ericaceae | S5 | 7 | 0 | 1 | 2 | 0 | 3 | 4 | 13 |
| *Vaccinium oxycoccos* | Ericaceae | S5 | 68 | 0 | 40 | 30 | 31 | 27 | 5 | 196 |
| *Vaccinium vitis-idaea* | Ericaceae | S5 | 50 | 25 | 14 | 175 | 27 | 42 | 6 | 333 |
| *Viburnum nudum var. cassinoides* | Caprifoliaceae | S5 | 0 | 42 | 13 | 2 | 14 | 8 | 5 | 79 |
| *Viola sororia* | Violaceae | S5 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 |

**Appendix B.** A complete list of the 43 lichen species found at the plot level across six coastal barren sites (Peggy's Cove, Chebucto Head, Taylor Head, Canso, Little Anse, and Baleine). SRANKs (where available) are from the Atlantic Canada Conservation Data Centre (2006). Columns 4-9 indicate the number of times a species was found at a site. Column 10 indicates how many sites contained each species. The last column indicates the total number of times each species was encountered during sampling across all six sites.

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Arctoparmelia centrifuga* | Parmeliaceae | . | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 2 |
| *Bryoria trichodes* | Parmeliaceae | . | 0 | 9 | 0 | 0 | 0 | 0 | 1 | 9 |
| *Cetraria aculeata* | Parmeliaceae | . | 5 | 1 | 0 | 1 | 2 | 0 | 4 | 9 |
| *Cetraria islandica* | Parmeliaceae | . | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Cladonia arbuscula* | Cladoniaceae | . | 4 | 0 | 1 | 4 | 1 | 4 | 5 | 14 |
| *Cladonia boryii* | Cladoniaceae | . | 1 | 0 | 48 | 1 | 45 | 0 | 4 | 95 |
| *Cladonia chlorophaea* | Cladoniaceae | . | 1 | 3 | 0 | 3 | 1 | 0 | 4 | 8 |
| *Cladonia crispata* | Cladoniaceae | . | 1 | 18 | 1 | 1 | 1 | 0 | 5 | 22 |
| *Cladonia cristatella* | Cladoniaceae | . | 0 | 1 | 0 | 8 | 0 | 0 | 2 | 9 |
| *Cladonia glauca* | Cladoniaceae | . | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| *Cladonia maxima* | Cladoniaceae | . | 18 | 4 | 0 | 4 | 1 | 15 | 5 | 42 |
| *Cladonia mitis* | Cladoniaceae | . | 2 | 2 | 2 | 16 | 13 | 1 | 6 | 36 |
| *Cladonia pyxidata* | Cladoniaceae | . | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 3 |
| *Cladonia rangiferina* | Cladoniaceae | . | 61 | 11 | 0 | 160 | 20 | 15 | 5 | 267 |
| *Cladonia rappii* | Cladoniaceae | . | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Cladonia squamosa* | Cladoniaceae | . | 5 | 19 | 3 | 0 | 6 | 5 | 5 | 38 |
| *Cladonia stellaris* | Cladoniaceae | . | 1 | 0 | 0 | 0 | 8 | 0 | 2 | 9 |
| *Cladonia strepsilis* | Cladoniaceae | . | 0 | 0 | 3 | 0 | 1 | 0 | 2 | 4 |
| *Cladonia stygia* | Cladoniaceae | . | 36 | 0 | 0 | 2 | 1 | 11 | 4 | 50 |
| *Cladonia terrae-novae* | Cladoniaceae | . | 92 | 26 | 56 | 68 | 135 | 289 | 6 | 666 |
| *Cladonia uncialis* | Cladoniaceae | . | 13 | 0 | 8 | 12 | 12 | 8 | 5 | 53 |
| *Hypogymnia krogiae* | Parmeliaceae | . | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 2 |
| *Hypogymnia physodes* | Parmeliaceae | . | 1 | 66 | 4 | 6 | 2 | 3 | 6 | 82 |
| *Hypogymnia tubulosa* | Parmeliaceae | . | 0 | 11 | 0 | 0 | 0 | 0 | 1 | 11 |
| *Lasallia papulosa* | Umbilicariaceae | . | 0 | 0 | 3 | 0 | 1 | 0 | 2 | 4 |

| *Species* | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Melanelia stygia* | Parmeliaceae | . | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Ochrolechia frigida* | Pertusariaceae | . | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Parmelia saxatilis* | Parmeliaceae | . | 0 | 0 | 2 | 2 | 0 | 0 | 2 | 4 |
| *Parmelia squarrosa* | Parmeliaceae | . | 0 | 17 | 0 | 2 | 0 | 0 | 2 | 6 |
| *Parmelia sulcata* | Parmeliaceae | . | 0 | 3 | 0 | 2 | 0 | 1 | 3 | 19 |
| *Plasmatia glauca* | Parmeliaceae | . | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| *Ramalina dilacerata* | Ramalinaceae | . | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 |
| *Ramalina roesleri* | Ramalinaceae | . | 0 | 6 | 0 | 1 | 0 | 0 | 2 | 7 |
| *Stereocaulon dactylophyllum* | Stereocaulaceae | S4 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Stereocaulon saxatile* | Stereocaulaceae | S5 | 0 | 1 | 4 | 0 | 0 | 0 | 2 | 5 |
| *Umbilicaria muehlenbergii* | Umbilicariaceae | . | 0 | 14 | 7 | 0 | 1 | 0 | 3 | 22 |
| *Usnea ceratina* | Parmeliaceae | . | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| *Usnea filipendula* | Parmeliaceae | . | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Usnea sp. 1* | Parmeliaceae | . | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Usnea sp. 2* | Parmeliaceae | . | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Usnea subfloridana* | Parmeliaceae | . | 0 | 36 | 0 | 0 | 0 | 0 | 1 | 36 |
| *Usnea trichodea* | Parmeliaceae | . | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| lichen 1 | | . | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 2 |

**Appendix C.** A complete list of the 28 moss species found at the plot level across six coastal barren sites (Peggy's Cove, Chebucto Head, Taylor Head, Canso, Little Anse, and Baleine). SRANKs (where available) are from the Atlantic Canada Conservation Data Centre (2006). Columns 4-9 indicate the number of times a species was found at a site. Column 10 indicates how many sites contained each species. The last column indicates the total number of times each species was encountered during sampling across all six sites.

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Brachythecium velutinum* | Brachytheciaceae | . | 2 | 9 | 0 | 0 | 0 | 0 | 2 | 11 |
| *Dicranum ontariense* | Dicranaceae | . | 0 | 10 | 5 | 0 | 1 | 0 | 3 | 16 |
| *Dicranum polysetum* | Dicranaceae | . | 2 | 2 | 0 | 1 | 3 | 4 | 5 | 12 |
| *Dicranum scoparium* | Dicranaceae | . | 2 | 4 | 0 | 0 | 0 | 3 | 3 | 9 |
| *Dicranum undulatum* | Dicranaceae | . | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| *Herzogiella turfacea* | Hypnaceae | . | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Hylocomium splendens* | Hylocomiaceae | . | 0 | 2 | 0 | 4 | 0 | 1 | 3 | 7 |
| *Hypnum imponens* | Hypnaceae | . | 0 | 2 | 0 | 0 | 3 | 0 | 2 | 5 |
| *Leskea polycarpa* | Leskeaceae | . | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| *Leucobryum glaucum* | Leucobryaceae | . | 0 | 5 | 11 | 0 | 1 | 3 | 4 | 20 |
| *Pleurozium schreberi* | Hylocomiaceae | . | 4 | 21 | 4 | 73 | 1 | 66 | 6 | 169 |
| *Polytrichum commune* | Polytrichaceae | . | 0 | 0 | 0 | 23 | 0 | 0 | 1 | 23 |
| *Racomitrium canescens* | Grimmiaceae | S2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| *Racomitrium lanuginosum* | Grimmiaceae | S2S3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| *Sphagnum angermanicum* | Sphagnaceae | . | 0 | 0 | 0 | 0 | 17 | 0 | 1 | 17 |
| *Sphagnum angustifolium* | Sphagnaceae | S1 | 0 | 0 | 0 | 11 | 0 | 0 | 1 | 11 |
| *Sphagnum capillifolium* | Sphagnaceae | . | 0 | 5 | 2 | 2 | 18 | 15 | 5 | 42 |
| *Sphagnum compactum* | Sphagnaceae | . | 16 | 0 | 5 | 4 | 0 | 0 | 3 | 25 |
| *Sphagnum fallax* | Sphagnaceae | . | 4 | 0 | 29 | 0 | 4 | 0 | 3 | 37 |
| *Sphagnum flavicomans* | Sphagnaceae | S2 | 0 | 0 | 0 | 0 | 8 | 0 | 1 | 8 |
| *Sphagnum fuscum* | Sphagnaceae | . | 37 | 0 | 59 | 0 | 26 | 25 | 4 | 147 |
| *Sphagnum imbricatum* | Sphagnaceae | S2 | 8 | 1 | 4 | 0 | 7 | 13 | 5 | 33 |
| *Sphagnum magellanicum* | Sphagnaceae | . | 12 | 0 | 7 | 17 | 8 | 11 | 5 | 55 |
| *Sphagnum papillosum* | Sphagnaceae | . | 0 | 0 | 0 | 0 | 8 | 0 | 1 | 8 |

| Species | Family | SRANK | BA | CA | CH | LI | PE | TA | # sites where found | total # times recorded |
|---|---|---|---|---|---|---|---|---|---|---|
| *Sphagnum rubellum* | Sphagnaceae | . | 0 | 0 | 0 | 0 | 28 | 9 | 2 | 37 |
| *Sphagnum russowii* | Sphagnaceae | . | 0 | 0 | 0 | 0 | 5 | 0 | 1 | 5 |
| liverwort *(Ptilidium pulcherrimum)* | | . | 5 | 0 | 0 | 29 | 0 | 1 | 3 | 35 |
| moss sp. 1 | . | . | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

**Appendix D**. Plot-level species richness (total number of species per plot) for all species, vascular plants, lichens, and mosses, as well as total richness per plot.

| PLOT | TOTAL RICHNESS | Vascular plants | Lichens | Mosses |
|---|---|---|---|---|
| BA-01 | 7 | 7 | 0 | 0 |
| BA-02 | 12 | 11 | 1 | 0 |
| BA-03 | 20 | 14 | 6 | 0 |
| BA-04 | 15 | 10 | 4 | 1 |
| BA-05 | 12 | 10 | 2 | 0 |
| BA-06 | 20 | 14 | 4 | 2 |
| BA-07 | 21 | 12 | 6 | 3 |
| BA-08 | 19 | 13 | 6 | 0 |
| BA-09 | 17 | 12 | 3 | 2 |
| BA-10 | 19 | 14 | 5 | 0 |
| BA-11 | 17 | 13 | 2 | 2 |
| BA-12 | 16 | 16 | 0 | 0 |
| BA-13 | 9 | 9 | 0 | 0 |
| BA-14 | 14 | 14 | 0 | 0 |
| BA-15 | 25 | 20 | 4 | 1 |
| BA-16 | 22 | 15 | 6 | 1 |
| BA-17 | 23 | 16 | 4 | 3 |
| BA-18 | 18 | 12 | 4 | 2 |
| BA-19 | 25 | 13 | 9 | 3 |
| BA-20 | 18 | 10 | 5 | 3 |
| CA-01 | 16 | 16 | 0 | 0 |
| CA-02 | 21 | 18 | 0 | 3 |
| CA-03 | 16 | 14 | 0 | 2 |
| CA-04 | 18 | 18 | 0 | 0 |
| CA-05 | 21 | 11 | 9 | 1 |
| CA-06 | 25 | 16 | 6 | 3 |
| CA-07 | 15 | 14 | 0 | 1 |
| CA-08 | 19 | 16 | 1 | 2 |
| CA-09 | 17 | 17 | 0 | 0 |
| CA-10 | 11 | 2 | 4 | 5 |
| CA-11 | 22 | 12 | 2 | 8 |
| CA-12 | 18 | 11 | 6 | 1 |
| CA-13 | 12 | 12 | 0 | 0 |
| CA-14 | 19 | 12 | 4 | 3 |
| CA-15 | 18 | 11 | 7 | 0 |
| CA-16 | 15 | 11 | 3 | 1 |
| CA-17 | 20 | 15 | 5 | 0 |
| CA-18 | 16 | 15 | 0 | 1 |
| CA-19 | 14 | 13 | 0 | 1 |
| CA-20 | 13 | 9 | 4 | 0 |
| CH-01 | 6 | 6 | 0 | 0 |
| CH-02 | 13 | 13 | 0 | 0 |
| CH-03 | 15 | 14 | 0 | 1 |
| CH-04 | 12 | 11 | 1 | 0 |
| CH-05 | 18 | 13 | 4 | 1 |
| CH-06 | 12 | 6 | 6 | 0 |
| CH-07 | 13 | 10 | 2 | 1 |

| PLOT | TOTAL RICHNESS | Vascular plants | Lichens | Mosses |
|---|---|---|---|---|
| CH-08 | 15 | 9 | 5 | 1 |
| CH-09 | 27 | 20 | 3 | 4 |
| CH-10 | 23 | 17 | 1 | 5 |
| CH-11 | 2 | 1 | 1 | 0 |
| CH-12 | 13 | 5 | 7 | 1 |
| CH-13 | 16 | 15 | 0 | 1 |
| CH-14 | 17 | 13 | 4 | 0 |
| CH-15 | 15 | 11 | 3 | 1 |
| CH-16 | 12 | 12 | 0 | 0 |
| CH-17 | 17 | 14 | 1 | 2 |
| CH-18 | 15 | 11 | 2 | 2 |
| CH-19 | 15 | 12 | 1 | 2 |
| CH-20 | 13 | 9 | 2 | 2 |
| LI-01 | 12 | 7 | 4 | 1 |
| LI-02 | 14 | 10 | 4 | 0 |
| LI-03 | 11 | 8 | 2 | 1 |
| LI-04 | 9 | 8 | 1 | 0 |
| LI-05 | 10 | 10 | 0 | 0 |
| LI-06 | 14 | 12 | 0 | 2 |
| LI-07 | 16 | 13 | 0 | 3 |
| LI-08 | 17 | 15 | 0 | 2 |
| LI-09 | 11 | 7 | 4 | 0 |
| LI-10 | 12 | 7 | 3 | 2 |
| LI-11 | 13 | 7 | 4 | 2 |
| LI-12 | 16 | 8 | 6 | 2 |
| LI-13 | 15 | 8 | 4 | 3 |
| LI-14 | 17 | 12 | 3 | 2 |
| LI-15 | 17 | 10 | 5 | 2 |
| LI-16 | 10 | 6 | 3 | 1 |
| LI-17 | 12 | 7 | 3 | 2 |
| LI-18 | 13 | 8 | 3 | 2 |
| LI-19 | 15 | 9 | 2 | 4 |
| LI-20 | 27 | 12 | 10 | 5 |
| PE-01 | 17 | 16 | 1 | 0 |
| PE-02 | 19 | 19 | 0 | 0 |
| PE-03 | 18 | 17 | 1 | 0 |
| PE-04 | 16 | 14 | 2 | 0 |
| PE-05 | 19 | 17 | 2 | 0 |
| PE-06 | 20 | 11 | 9 | 0 |
| PE-07 | 2 | 0 | 2 | 0 |
| PE-08 | 28 | 24 | 1 | 3 |
| PE-09 | 24 | 21 | 2 | 1 |
| PE-10 | 16 | 9 | 7 | 0 |
| PE-11 | 13 | 9 | 4 | 0 |
| PE-12 | 14 | 9 | 5 | 0 |
| PE-13 | 16 | 12 | 3 | 1 |
| PE-14 | 16 | 11 | 4 | 1 |
| PE-15 | 20 | 14 | 4 | 2 |
| PE-16 | 20 | 14 | 2 | 4 |

| PLOT | TOTAL RICHNESS | Vascular plants | Lichens | Mosses |
|---|---|---|---|---|
| PE-17 | 24 | 21 | 0 | 3 |
| PE-18 | 18 | 16 | 0 | 2 |
| PE-19 | 15 | 12 | 0 | 3 |
| PE-20 | 25 | 19 | 2 | 4 |
| TA-01 | 2 | 2 | 0 | 0 |
| TA-02 | 12 | 8 | 3 | 1 |
| TA-03 | 24 | 17 | 4 | 3 |
| TA-04 | 22 | 19 | 2 | 1 |
| TA-05 | 13 | 10 | 2 | 1 |
| TA-06 | 19 | 15 | 1 | 3 |
| TA-07 | 24 | 21 | 0 | 3 |
| TA-08 | 21 | 13 | 6 | 2 |
| TA-09 | 25 | 14 | 6 | 5 |
| TA-10 | 18 | 14 | 2 | 2 |
| TA-11 | 25 | 21 | 0 | 4 |
| TA-12 | 19 | 16 | 1 | 2 |
| TA-13 | 13 | 11 | 1 | 1 |
| TA-14 | 20 | 16 | 3 | 1 |
| TA-15 | 14 | 11 | 2 | 1 |
| TA-16 | 20 | 13 | 4 | 3 |
| TA-17 | 14 | 6 | 4 | 4 |
| TA-18 | 14 | 13 | 0 | 1 |
| TA-19 | 13 | 12 | 1 | 0 |
| TA-20 | 18 | 13 | 3 | 2 |

**Appendix E.** Topographic map data superimposed over 1:10,000 aerial photos of six coastal barren sites in Nova Scotia. Sampled plots are shown for each site.

**i. Aerial photos:**

| Site | Photo number |
|---|---|
| Baleine | 98323 171 L-58-2 98-07-19 11G/13 |
| Canso | 98302 192 L-23 98-06-12 11F/6 |
| Chebucto Head | 02321 230 L-6 02-07-26 11D/12 |
| Little Anse | 98304 16 L-26 98-06-14 11F/7 |
| Peggy's Cove | 02322 8 L-5 02-08-02 11D/5 |
| Taylor Head | 03303 92 L-10 03-06-29 11D/15 |



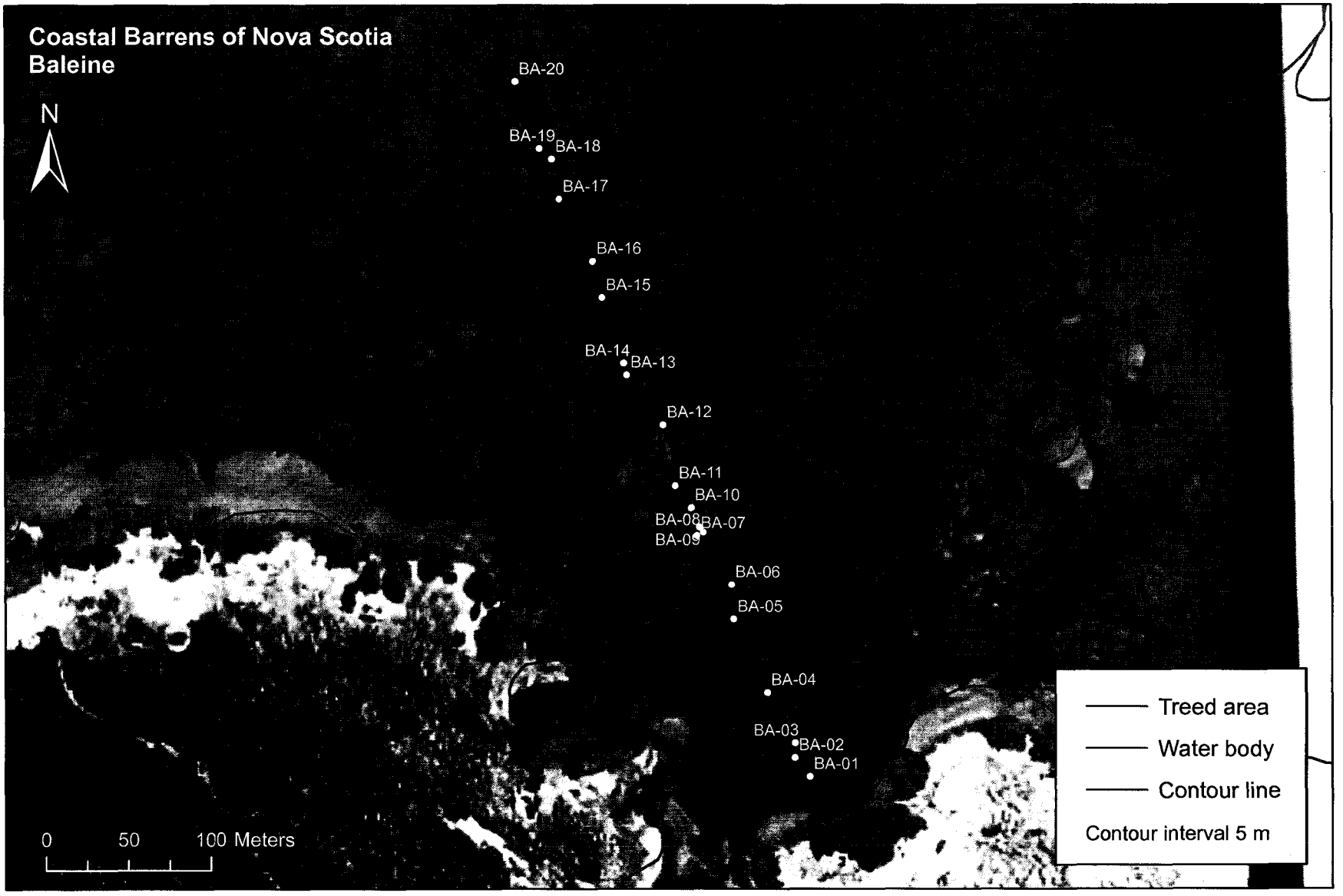
**ii. Topographic maps:**

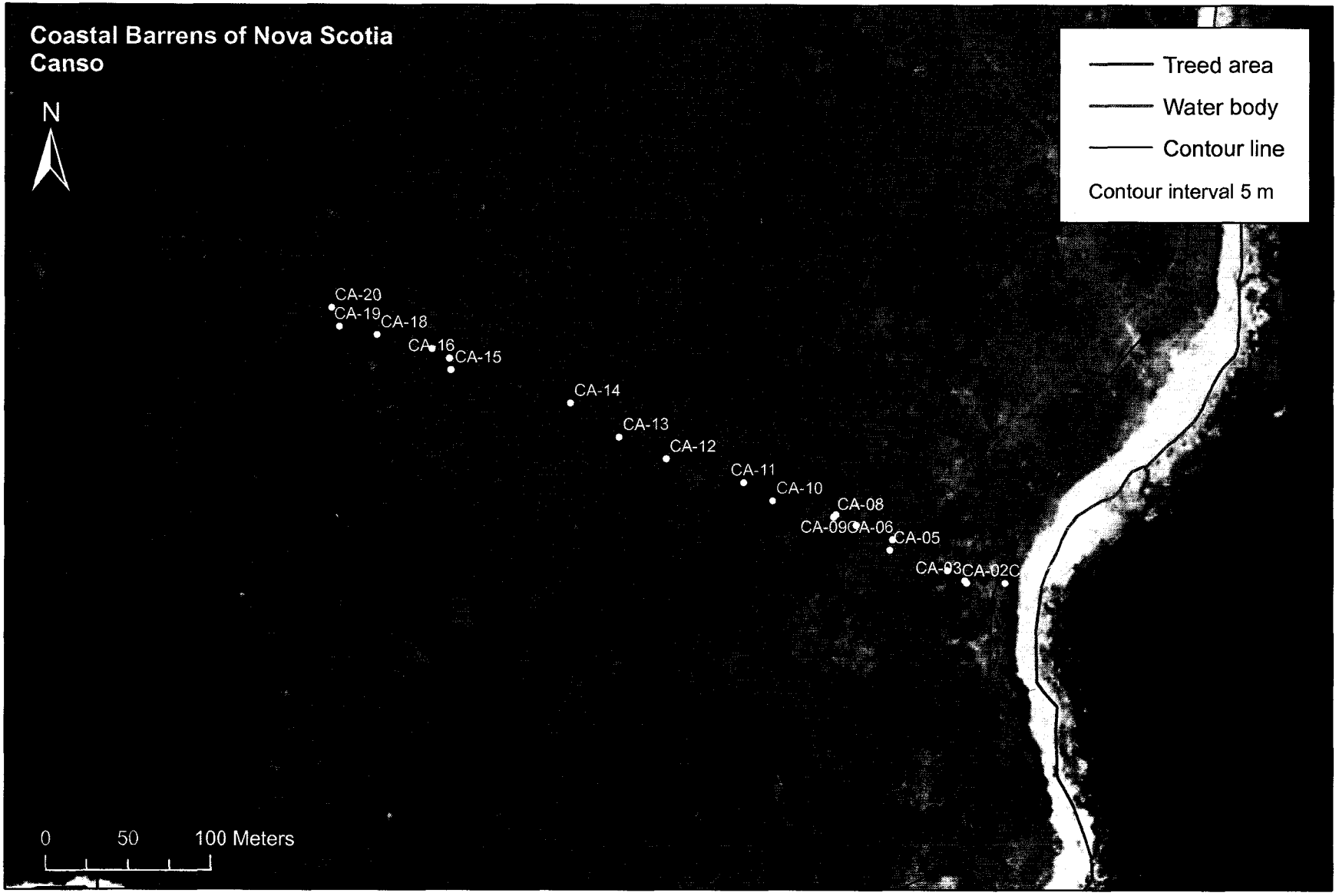
| Site | Mapsheet | Map name |
|---|---|---|
| Baleine | 1045900059800 | Baleine Road |
| Canso | 1045250061000 | Dover |
| Chebucto Head | 1044500063500 | Portuguese Cove |
| Little Anse | 1045450060900 | Little Anse |
| Peggy's Cove | 1044450063800 | West Dover |
| Taylor Head | 1044750062500 | Taylor Head |

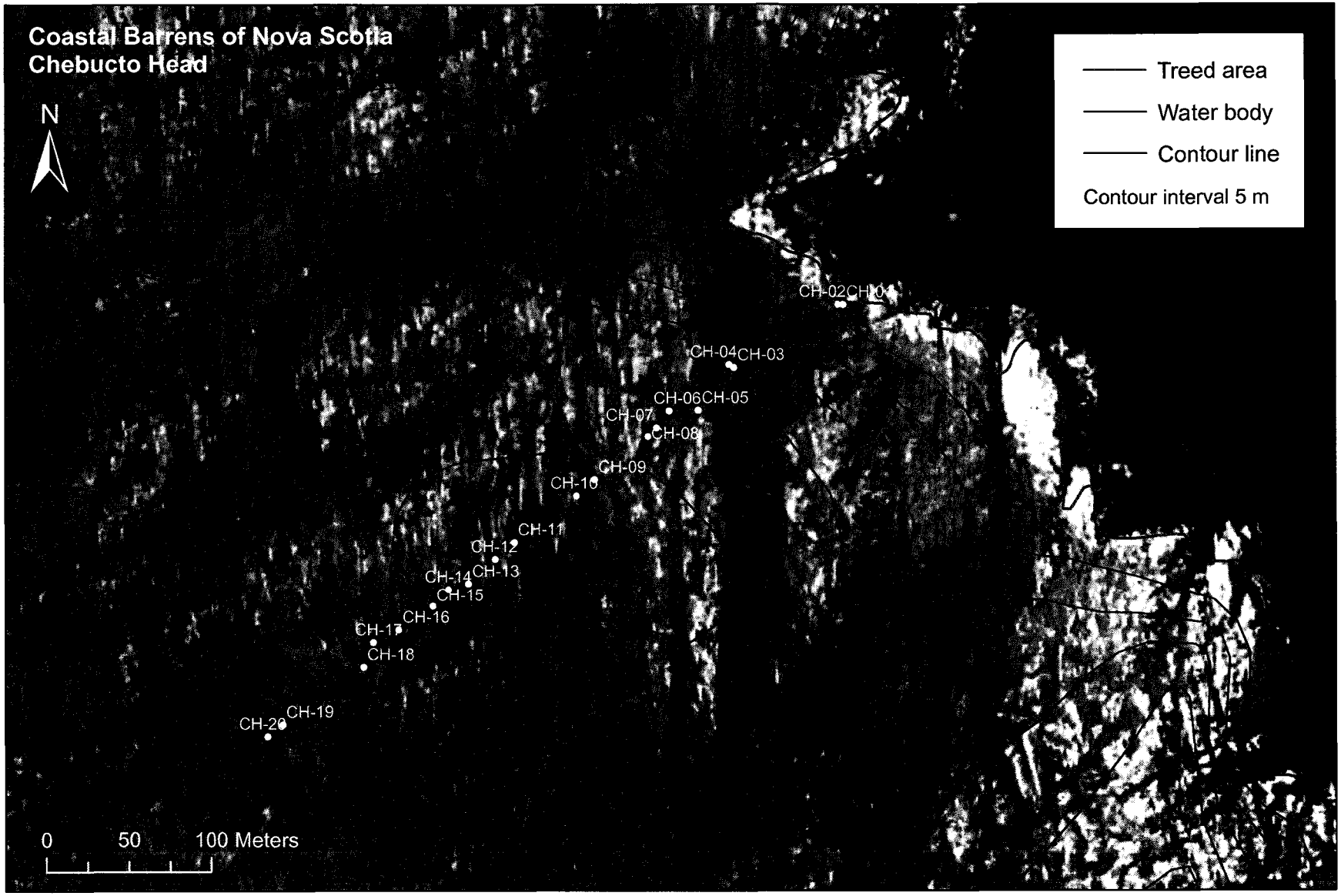


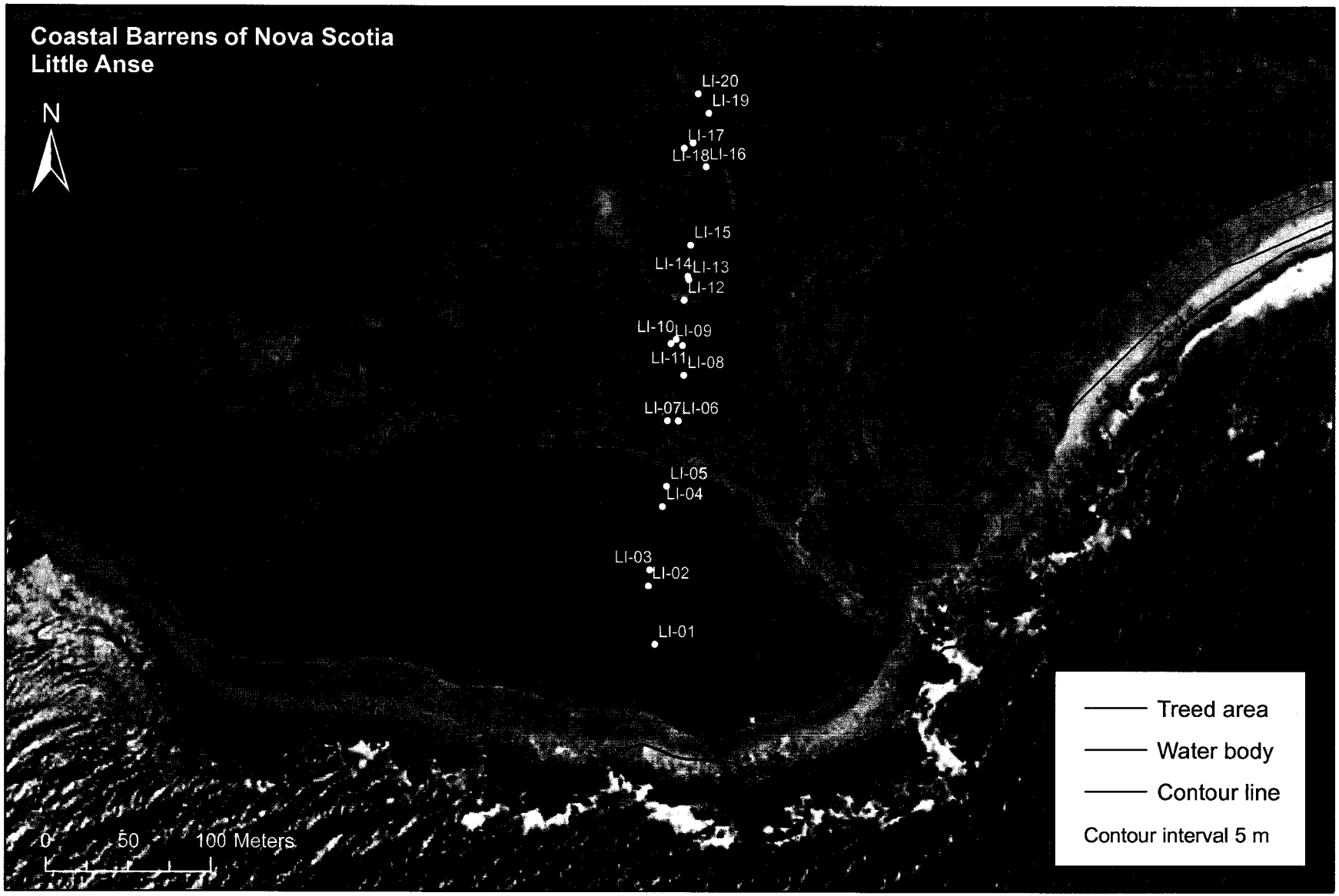
**iii. Plot coordinates for the southwest corner of plot 01 at each sampled site:**

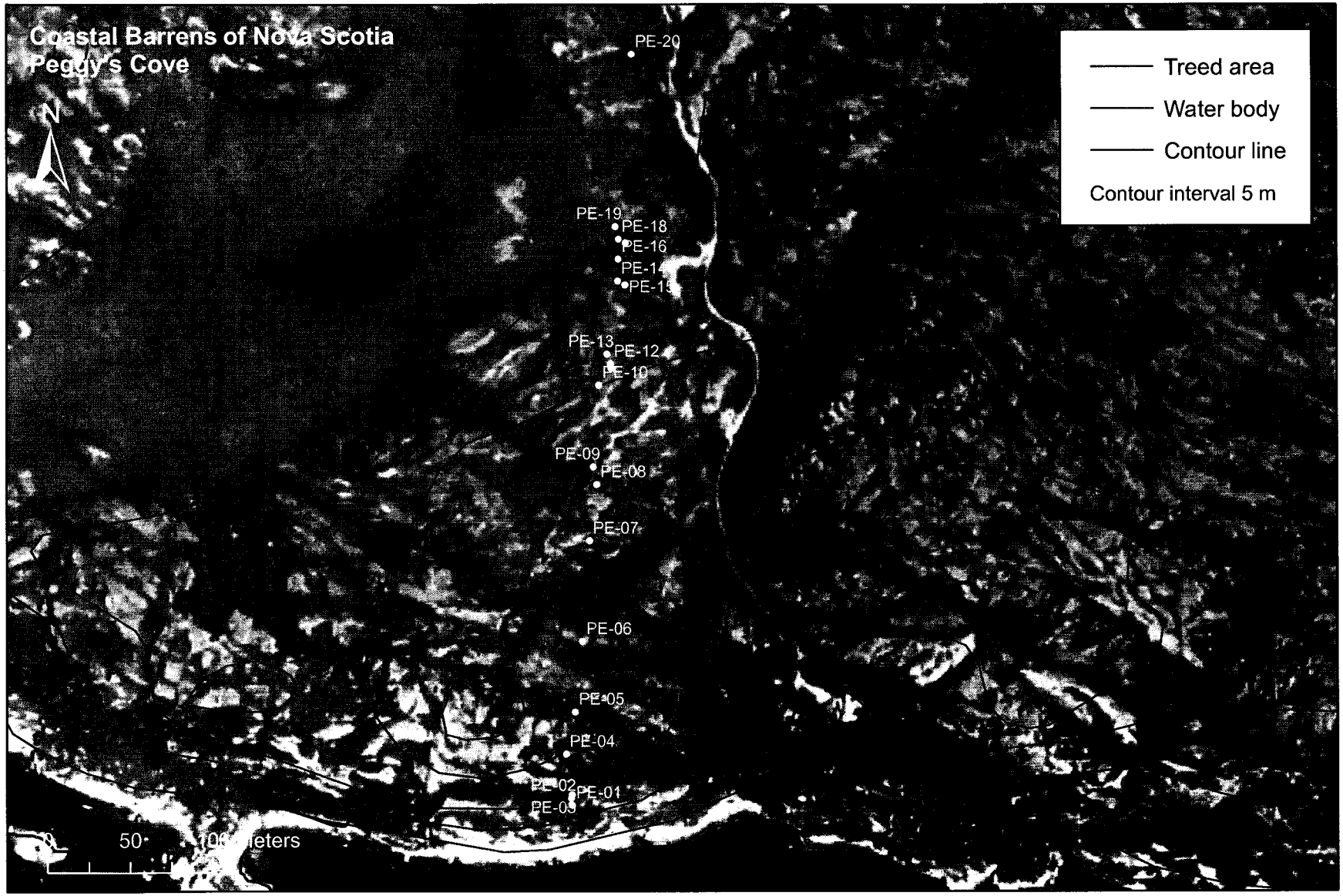
| Site | Plot | UTM |
|---|---|---|
| Baleine | BA-01 | 45° 56' 33.5904", 59° 49' 4.1520" |
| Canso | CA-01 | 45° 15' 25.4556", 61° 2' 2.7924" |
| Chebucto Head | CH-01 | 44° 30' 40.5684", 63° 31' 32.4589 |
| Little Anse | LI-01 | 45° 28' 46.2396", 60° 56' 56.2560" |
| Peggy's Cove | PE-01 | 44° 29' 20.8465", 63° 53' 26.7432" |
| Taylor Head | TA-01 | 44° 47' 55.6547", 62° 33' 51.7716" |

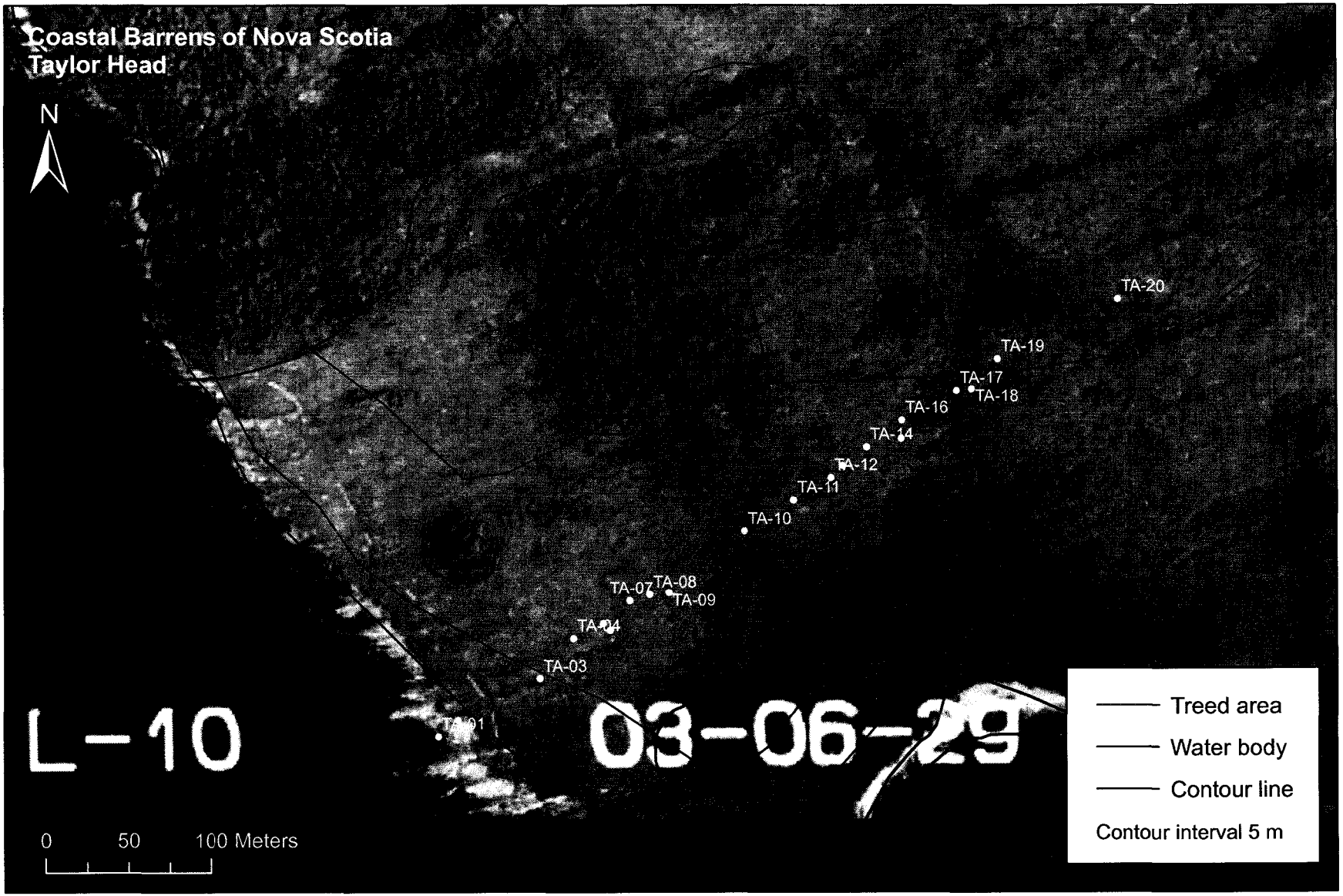












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